AN EVALUATION OF DIGITIZER—NON—METRIC CAMERA SYSTEM IN CLOSE—RANGE PHOTOGRAMMETRY

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by

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CERTIFICATE

This is to certify that the thesis entitled, "AN EVALUATION OF DIGITIZER - NON-METRIC CAMERA SYSTEM IN CLOSE-RANGE PHOTOGRAMMETRY" submitted by Shri S.Subramanya in partial fulfilment of the requirements for the degree of Master of Technology, at the Indian Institute of Technology, Kanpur, is a record of bonafide research work carried by him under my supervision and guidance. The work embodied in this thesis has not been submitted elsewhere for a degree.

April, 1988.

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ABSTRACT

Immense cost of the equipment, incapability of smaller sized organisations to own them, has resulted in a great search for inexpensive and easily available photogrammetric equipment and methods. This has led to the discovery of the use of Amateaur cameras in place of Costlier Metric Cameras for photography. Yet the photogrammetric machines such as the comparators used for measuring coordinates of the image points remain the expensive component of the system.

An attempt has been hereby made to evaluate the photogrammetric potentials of an inexpensive Nonmetric camera - Tablet digitizer combination. Both are cheaply and easily available. Further they can be made use of for many other purposes other than photogrammetry.

Camera-enlarger system was calibrated using a target field prepared in the laboratory. Calibration results indicated the influence of the enlarger lens distortion characteristics. No significant change was found from exposure to exposure. Principal point off-sets were negligibly small. The RMS values of the check points (8.6 microns, 7.3 microns and 2.136/1000 in X, Y and Z directions respectively) indicated that this inexpensive system can give comparable results with any of the photogrammetric machines. Experiments in Graphics indicated a great potential of the system in mapping objects by contouring.

INTRODUCTION

Photogrammetry is derived from three Greek words namely,

Photos - light

Gramma - drawn

Metron - to measure

-meaning drawing and measuring with the help of light rays. Manual of photogrammetry defines photogrammetry as the art, science and technology of obtaining reliable information about physical objects and environment through the processes of Recording, Measuring and Interpreting images and patterns of Electromagnetic radiant energy and other phenomena.

Recording is accomplished by the use of a camera by a process called photography. The product of photography is a photograph. Depending upon the purpose, photography may be Terrestrial, Aerial or Orbital. A variety of photogrammetric machines are available for recording, measuring and plotting in the form of photogrammetric cameras, comparators and plotters, whose precision, complexity and hence the cost depends upon the application for which they are made. Interpretation is descriptive and hence outside the scope of this work.

Close-range photogrammetry is a branch of photogrammetry where the object-to-camera distances are less than 300 meters. It encompasses Industrial photogrammetry, Architectural photogrammetry and Biostereometrics .

Close-range photogrammetry, also called as non-topographical photogrammetry is associated with such diversified fields as Animal husbandry, Architecture, Archeology, Bacteriology, Criminology, Deformation of objects, Hydraulics, Marine structures, Geology, Geotechnical Engineering, Nuclear Physics, Aerodynamics, Ship building, Antennae Measurements, Medicine, Dentistry, Material science etc. The reasons for such a wide range of applications being.

1. It is the only non-contact method and through a choice of supplementary measurements the need for the direct contact with the object being analysed can be avoided.
2. The photographic document is available for second thought measurements at a later stage of photogrammetry.
3. A single picture taken represents measuring infinite number of horizontal and vertical angles from the same station with a theodolite. Thus the field work is reduced to a minimum.
4. Measurement on prototype is very difficult in the case of modern buildings and structures because of the complexity of design. Photogrammetry can be used under such circumstances

5. Photogrammetric methods do not obstruct the normal functioning of the structure being analysed.
6. Measurements can be made up to the very end. i.e. until the failure of a structure, for example.
7. It can be the best way and perhaps the only way to measure
   (a) Irregular shapes
   (b) Moving shapes
   (c) Inflated shapes
   (d) Objects that are too cold, too hot, too delicate, too soft, too inaccessible, too toxic and too radioactive to touch.

This wide range of applications of close-range photogrammetry calls for a wide variety of photogrammetric machines, and it is not economically justifiable for the manufacturers of such machines to offer as many different types of machinery as would be necessary to cover the wide spectrum of requirements of various applications.

Even the available equipment for photogrammetric work are very costly. The cost increases in direct proportion with the precision of the machines. Very precise machines are required since the object space distances are scaled down in photography and any error or inaccuracy crept in is magnified many a folds, resulting in totally erroneous results which may become useless to the user community.

Photogrammetric techniques of working require the taking of atleast two overlapping photographs, through a camera of

known inner orientation (i.e. having a knowledge of the Fiducial marks and the Calibrated Focal Length). Such photographs when viewed stereoscopically depict a three dimensional model of the photographed object space. The knowledge of the inner orientation parameters permits the fixing of origin and a datum with reference to which the three dimensional measurements may be obtained.

A precise camera with exactly known inner orientation requires a sophisticated assemblage. Thus in order to have a camera with metric qualities very expensive set up is needed which is beyond the reach of small sized organisations. Not only the camera, but also the photogrammetric machine in which the said overlapping photographs are to be inserted to obtain the three dimensional model are equally expensive.

A combination of such camera-photogrammetric machine set-up may cost many hundred thousands of rupees to acquire. This is beyond the reach of many organizations and inspite of knowing the vast potential of its capabilities, particularly due to cost factor and then due to lack of trained man power, such versatile techniques as offered by photogrammetric techniques have not been able to become popular, except in topographic mapping, generally done by National Organizations.

Non-metric or simply Amateaur cameras are not the cameras especially made for the photogrammetric purposes. They have

certain advantages and disadvantages as compared to metric cameras which are especially made for photogrammetric purposes. Hence to obtain measurements from them is difficult and not as accurate as desired. Research is still continuing to find practical methods of using Non-metric cameras for metric purposes. Combination of methods with analytical techniques of photogrammetric solutions has gained popularity in recent years. But most investigations centre around the comparators and the analytical plotters.

A modest effort has been made through this investigation, to evaluate,if a comparatively very inexpensive set-up of an ordinary Amateaur Camera - Digitizer combination can substitute the well established combination of metric camera - photogrammetric machines. If this combination can be made effective it is felt that it will provide a considerable break through in overcoming the need of expensive photogrammetric machines for mapping purposes, due to the advantage that microcomputers and digitizers are easily and cheaply available, and when acquired by moderately sized organizations, can be made use of for various other purposes, apart from the listed use of mapping as is prevailant with metric camera-photogrammetric machine combination. The amateaur cameras which are inexpensive are also easily available, in flexible ranges of focal lengths and are easier to handle and transport apart from the fact that photography with them is far less complicated than with metric photogrammetric cameras.

However amateaur cameras and cartographic Tablet digitizers have their own limitations. In amateaur cameras the lenses are designed for higher resolution at the expense of distortion. In these the inner orientation is also unstable. Further they lack the Fiducial marks, level bubbles, orientation provisions and the film flattening device. The resolution of a cartographic Tablet digitizer is too low and hence cannot be used in the case of very small scale photography. Also continuous mapping is not possible.

It is due to such inherent inaccuracies of the equipment, that very high accuracy may not be expected in comparison to the most sophisticated photogrammetric machines and methods. But this study will establish the possibly achievable accuracy. It is nevertheless expected that this method should provide a highly cost effective and comparitively accurate system of mapping with the help of discretely co-ordinated points.

LITERATURE REVIEW

Photogrammetric Potentials of Non-metric Cameras

Photogrammetry is general has a long and interesting history which starts from as early as 350 B.C. (Wolf, 1985; Gruner, 1977). However many discoveries were made and the use of non-metric cameras for close-range applications became popular during 1970's and 1980's (Kennert et al 1976; Karara, 1985).

Number of experiments conducted during the above period have proved that non-metric camera can be used for photogrammetric purposes, provided that the camera is appropriately calibrated, sufficient object space control is used and analytical methods are used for data reduction. A method particularly suitable for non-metric photogrammetry has been suggested (Karara, 1972) in which the comparator co-ordinates are directly transformed into the object space co-ordinates without the intermediary step of transforming them into photo-coordinates. Thus the fiducial marks are not necessary. These 'Direct Linear Transformation' equations do not require linearisation and hence economical as regards the computer time.

In an attempt to evaluate four non-metric cameras and one metric camera an updated version of Direct Linear Transformation (DLT) has been used which includes six models of image refinement (Karara et al, 1974). Experiments have proved

that the model for image refinement, for nonmetric cameras, of the following form will be quite appropriate and sufficient.

$$\Delta x = a_1 + a_2 x + a_3 y + \bar{x}\, k\, r^2 \qquad \Delta x, \Delta y = \text{Image refinement parameters}$$

$$\Delta y = a_4 + a_5 x + a_6 y + \bar{y}\, k\, r^2$$

where x and y are image coordinates, $\bar{x} = x - x_s$ and $\bar{y} = y - y_s$ where x_s and y_s are the image coordinates of the principal point, $r = (x^2+y^2)^{1/2}$, a_1, a_2 etc. Film deformation coefficients, K_1 is lens distortion coefficient.

Experiments conducted on seven metric cameras to determine the tolerances for the principal point and the principal distance Lens distortions, Model accuracy and Reproducibility of the elements of inner orientation have proved that the difference between the accuracies of metric and non-metric cameras are very less and the accuracy parameters do not depend upon whether a camera is metric or non-metric but depend upon the cone angle (Kolbl, 1976). If smaller cone angles and analytical methods are used non-metric cameras can be used with almost the same precision as that of metric cameras. The predictor formula for accuracy proves beyond doubt that the best non-metric cameras can be compared to metric cameras as regards the accuracy (Hottier, 1976).

Calibration of Non-metric Cameras

It is evident from the above discussion that non-metric cameras have great potentials once they are calibrated. Thus

calibration becomes a 'Link' between nonmetric and metric cameras. Many methods have been developed for the calibration of nonmetric cameras. Even though partial calibration is some times used self and on the job calibrations or more popular, because of the instability of the inner orientation of nonmetric cameras. Instability of a nonmetric camera can be determined by using statistical methods (Nasu et al, 1976).

Amongst the partial calibration methods which uses a target field the "Analytical Plumb Line Method' developed by Brown is worth mentioning. The straightness or the lack of straightness of the plumbline can be used analytically to determine the inner orientation of both metric and nonmetric cameras (Brown, 1971). But in close-range photogrammetry often the object-to-camera distances on too small, or in other words the scales are too large. This creates a problem as it is very difficult to set the control points in the object space to the required accuracy. Partial and even on-the-job methods cannot be used under such circumstances and the self calibration method becomes inevitable (Faig, 1975). Using collinearity and coplanarity conditions self calibration method can be used which does not require control points as such.

One of the major disadvantages of a nonmetric camera as has been pointed out earlier is the lack of Fiducial marks. The fiducial marks are either to be introduced (Schmutter et al., 1970) or the methods that do not require Fiducial marks are to be used. Attempts have been made with reasonably

accurate results, to use the corners of the film format as fiducial marks (Goodrich, 1985). In one such attempt (Hatzopoulos, 1985), several points have been measured along the edges and then their intersection found out computationally. In Hatzopoulos's work olympus OM-2N 35 mm camera has thus been calibrated using DLT approach and Finite Element Method. A combination of the above calibration method and least squares bundle adjustment has given an accuracy of 1 in 7000 of the largest dimension of a building, which has been taken as an example.

Of late, the Finite Element Method, which is being used so extensively in other fields such as structural analysis etc. is finding its use in close-range photogrammetry also (Halim, Munjy, 1986a). In this method the entire image area is divided into a number of subdomains. Each sub-domain is considered to have a different Focal Length (Halim, Munjy, 1986b), thus eliminating the assumption that the distortions are uniform over the entire image area. Experimental results have shown that this method gives a good representation of systematic errors in analytical photogrammetry. It reduces the effects of film unflatness, which is a major source of error in non-metric cameras.

From a study of the literature it is found that many of the analytical approaches towards camera calibration of non-metric cameras, revolve around the projective equations in one form or the other, which form a most powerful tool in

analytical photogrammetry (Ghosh, 1979, Wolf, 1985; Methley, 1986; Rampal, 1987). Most of the methods involve compensation of systematic image co-ordinate errors by analytical models, incorporated into the photogrammetric projective equations. The parameters defining systematic errors are then recovered simultaneously with other projective parameters in a least square adjustment. But the self calibration method using Finite Element Method has certainly distinct advantages over other methods.

Film for Non-metric Cameras

Specially made optically flat glass plate coated with emulsion is the most geometrically stable imaging surface. However glass plates are heavy, cumbersome and difficult to store and handle. Thus films are becoming more and more popular. On an average,film has twice the coefficient of thermal expansion as compared to glass. The geometrical stability of a film depends upon the thickness of the base material and the emulsion. Thicker the base material, thinner the emulsion,higher will be the geometrical stability.

Smaller format cameras are becoming increasingly popular, for the ease they provide in handling and also for their distinct advantages they have over larger formats (Clegg,1975). As the non-metric cameras lack film flattening device the film distortion may be very high. Experiments conducted in this direction have shown that in nonmetric cameras with mechanical film flattening the deviation may be as high as 25-30 microns (Meier, 1978). Also when the films are processec

and stored in the commercial way the shrinkage will vary depending upon the processes involved (Abdel Aziz, 1975), Measurements on 35 mm film negatives can be made only with a precise comparator which can measure up to one micron. When comparators are not available other methods have to be adopted such as micrometer vernier scales (Janke, 1972) or cartographic distizers (Welch et al., 1983; Oimoen, 1987). Since the resolution is poor these cannot be used on a 35 mm negative and this 35 mm film is to be enlarged and projection printed on either lithe film or Bromide paper. This enlargement introduces additional errors (Needham et al. 1984) to aggravate the situation.

Some Practical Examples of the Application of Non-metric Cameras

As has been pointed out earlier non-metric close-range photogrammetry has a very wide range of applications. Since the camera can be hand held and oriented in any direction, it provides greater manouveribility. This is very much essential in the case of Architectural Photogrammetry since the approaches to architectural buildings and monuments are quite narrow and the elbow room is quite less. Sometimes the photographs have to be taken through the windows of the adjacent buildings or from roof tops (Schmutter et al 1970). Many examples can be found in literature. One such example is the use of a Rollei - Nonmetric camera with a 6 cms x 6 cms format, and using a roll film to map architectural buildings in Stockholm.

A glass plate with fiducial marks was inserted at the back of the camera which also served as a pressure plate. Analytical method employed, the plotting technique used and the difficulties involved in architectural photogrammetry have been fully described. It is not always necessary to have very complicated equipment for these purposes. Simple laboratory fabricated equipment can be effectively used to make measurements on photographs (Janke, 1972).

Mines, Glaciers, Hilly terrains pose a different type of problem even though the result is the same. The hazardous nature of the above precludes the use of conventional methods of mapping, or even the use of a metric camera which invariably is heavy along with the other supporting equipment. Manouveribility and the speed are the prime factors in these cases and the hand held non-metric camera is best suited for this. Thus there is an example of the use of Yashika Model 'C' camera with a format of 55 x 55 mm and Canon 35 mm camera for mapping geological fractures and predicting the roof fall of Herrin No. 6 Coal Member in Illinois (Branden et al. 1976). DLT approach has been used for data reduction. Measurements were made on the original negatives using STK stereocomparator. The paper gives details about the analytical method used and results of the measurement of dip etc.

Similarly an Olympus OM-1 35 mm camera has been used for Glacier measurements in Sir Sanford range of Selkirk mountains, British Columbia (Goodrich, 1982). As the Glacier was totally inaccessible it was not possible to set the targets on the Glacier and some points that were already available were selected as control points. Since the accuracy required was very less (one foot) a calibrated parallax bar was used for measurements. Details of the camera calibration using the corners of window frames of a building which crossed the film format diagonally as targets, testing of the calibration of the camera using three dimensional field, are given.

Another example is the use of a Honey well Pentax spotmatic 35 mm SLR camera for photography and an Altek digitizer for co-ordinate measurement (Welch et al. 1983), for monitoring the channel erosion of Lampkin Branch, before and after a storm. Photographs were taken from a 9.5m high platform and with a camera base of 3.81 m, overlap 70% and with a Base/Depth ratio of 0.40. Average scale of the photography was 1:440 and hence the use of Altek AC 90 SM super micro digitizing system with a resolution of 25 microns gave quite acceptable results.

The above are but a few pointers to indicate the high photogrammetric potentials of non-metric cameras. Time and space do not permit the venture of going into deeper details. But it is felt that the above few examples bring out the tremendous advantages of a non-metric camera for recording purposes.

STATEMENT OF THE PROBLEM

III-1 INTRODUCTION

Study of photogrammetric potentials of non-metric cameras has been a topic of great interest to photogrammetrists world over for a long time. From time to time valuable studies have been performed but the method doesn't seem to have yet been standardised. There is found to be greater inclination of the photogrammetrists to try and find ways through which the fiducial marks may be introduced in simple photographic cameras to make them worthy of providing a co-ordinate system for measurement on the photographs.

Providing of fiducial marks to ordinary cameras is not an easy task. It may on the one hand not provide enough accuracy and on the other develop other complications due to tampering with the delicate camera assembly.

The recent trend therefore is to find ways to work without the fiducial marks in such cameras. Various research work has thus been published which deals with the combination of simple non-metric cameras and expensive photogrammetric machines. Since the photogrammetric machines remain the expensive component of the system, there still is the

reluctance on the part of scientists and photogrammetrists in small sized organisations to adopt to this method.

If there would be a system which is indigenously and easily available and can work as substitute to the above combination then it is expected that it will provide a very interesting, useful and inexpensive combination of resources.

III-2 OBJECTIVE OF THE THESIS

The objective of this thesis is therefore to evaluate the photogrammetric potentials of a 35 mm SLR Non-metric camera in conjunction with a digitizer attached to a micro-computer.

The aim of the work is to be able to establish a very inexpensive system which should be able to work as a substitute to extremely expensive set-up of metric camera and photogrammetric machines. Such a system can be easily acquired by any moderate sized organisation which may find this technique extremely handy method of mapping and measuring.

During the process of working, the 35 mm photographs have been enlarged by about 4.66 times through the already available Belvish photographic enlarger. For mapping purposes the Tectronix graphic system coupled to a Hewlett packard plotter would be utilised.

The work will be carried out in three distinct phases, viz.

1. Calibration of the camera-enlarger system.
2. Transformation of photo-coördinates which reference to the terrestrial control points and finding discrepancies over the check points.
3. Making use of available graphic programs and system capabilities for mapping and contouring an object.

The work is performed with particular reference to the close-range application of photogrammetry, but if successful the same concept and procedure can be extended to various other types of aerial and terrestrial photographs.

III-3 CALIBRATION OF CAMERA

Prior to use a camera is to be calibrated to determine some constants of the camera called "Elements of Inner Orientation". This is necessary for accurate data acquisition from the photographs.

For reliable photogrammetric measurements, there should be an exact correspondence between the light rays that enter the camera and the light rays that leave the lens to produce images on the focal plane. Thus the object of camera calibration is to determine the deviation of the image bundle so that corrections may be applied to the image bundle to get reliable information.

Following assumptions are made:

1. Photograph is a perspective projection, meaning that all the light rays entering the camera meet at a single point called the Exterior perspective centre.
2. The light rays entering the camera are straightlines, meaning that there is no refraction effect on the light rays. In the present case since the object to camera distances are very small the refraction effect has been neglected.
3. All the light rays from the lens leave from a single point called the Interior perspective centre, to produce image. The distance between the Interior perspective centre and the focal plane is called the Focal length of the camera.

Principal point is the foot of the perpendicular from the interior perspective centre of the lens to the focal plane. Principal point is also defined as the point where the camera axis meets the image plane.

Following are the elements of inner orientation:

1. Equivalent Focal Length (EFL): Focal length which is effective near the centre of the camera lens where the distortions are minimum.
2. Calibrated Focal Length (CFL): Focal length which produces an overall mean distribution of radial distortion.

3. Average radial lens distortion (dr): Distortion in image position along radial lines from the principal point.

4. Tangential lens distortion: Distortion in image position perpendicular to radial lines from the principal point. Since this distortion is very small compared to radial lens distortion this has been neglected in the present study (Wolf, 1985).

5. Principal point location: Co-ordinates of the principal point with respect to the x and y Fiducial axes. Although during manufacture of the camera care is taken to see that the principal point is exactly at the intersection of the Fiducial lines in metric cameras and at the centre of the format in non-metric cameras, usually there will be a little deviation from this condition.

6. Angle of intersection of Fiducial lines: This angle should be $90^{\circ} \pm 1'$ (Wolf, 1985).

To determine the above elements of inner orientation for a non-metric camera a number of methods are available which can be broadly classified into three groups (Kennert et al 1976).

1. Partial Calibration: This is usually performed in a laboratory using a test field or a target array. The selection of the number of parameters depends upon the accuracy required. The method is called partial since it does not consider the instability of the

elements of inner orientation.

2. On the Job Calibration utilises the photography taken of the object and the object space control simultaneously. Atleast one space control point (X, Y, Z) is required for every two unknown quantities included in the solution. Basically this makes use of the collinearity condition equations. Collinearity condition states that the object point, exposure station of any photograph and the photo image of the object point all lie on straight line.

Basic collinearity equations are

$$x_a = -f\left[\frac{m_{11}(X_A-X_L)+m_{12}(Y_A-Y_L)+m_{13}(Z_A-Z_L)}{m_{31}(X_A-X_L)+m_{32}(Y_A-Y_L)+m_{33}(Z_A-Z_L)}\right]$$

$$y_a = -f\left[\frac{m_{21}(X_A-X_L)+m_{22}(Y_A-Y_L)+m_{23}(Z_A-Z_L)}{m_{31}(X_A-X_L)+m_{32}(Y_A-Y_L)+m_{33}(Z_A-Z_L)}\right]$$

where

x_a, y_a = x and y coordinates of the image point in the photocoordinate system

X_A, Y_A, Z_A = X,Y,Z co-ordinates of the object point A

X_L, Y_L, Z_L = X,Y,Z co-ordinates of the exposure station.

$m_{11} \ldots m_{33}$ = Transformation coefficients which contain the rotational elements of the exposure station namely k, Ø and u .

For more details Appendix C may be referred.

3. Self-calibration: This differs from the above two methods in that it does not require object space control points as such for calibration. Three or more convergent photographs are taken and using the collinearity condition and well established object points the elements of interior orientation are determined.

Since the object of the present study is to evaluate the performance of non-metric camera-digitizer system and not the investigation of various camera calibration methods, the partial calibration method, which is comparatively simple, is used to calibrate the non-metric camera/camera enlarger system used in this experiment.

III-3.1 PROCEDURE ADOPTED FOR CAMERA CALIBRATION:

The target array used for calibration is shown in Fig. IV-1. The details of the experiment conducted including the description are given in Chapter Iv.

Since the above method is similar to the multicollimator method of camera calibration the central target mark image will herein be called the point of autocollimation. Because of the defects in the manufacture of non-metric cameras the optical axis of the camera may not meet the image plane exactly at this point, i.e. autocollimation. In other words the principal point and the point of autocollimation may not exactly coincide. This creates a problem in defining the origin

for measuring the co-ordinates of other target point images on the photograph. Hence for the co-ordinate measurement the point of autocollimation is considered as the origin (Karren, 1968).

III-3.2 ELEMENTS OF INTERIOR ORIENTATION

III-3.2.1 EQUIVALENT FOCAL LENGTH (EFL)

With reference to Fig. IV-1 if FG, FP, FQ and FE are the measured radial distances (r) around the point of autocollimation and along the four diagonals then

$$EFL = \frac{FG + FP + FQ + FE}{4 \tan\theta}$$

where 'θ' is the angle to the corresponding points (G,P,Q,E) subtended at the Exterior perspective centre of the camera. Thus,

$$EFL = \frac{\text{Average radial distance}}{\tan\theta}$$

The above is the condition when the points G, P, Q and E are equal angle points. But if the points are not equal angle points, then an average value for 'θ' is to be used in calculating EFL.

III-3.2.2 RADIAL LENS DISTORTION BASED UPON EFL:

Thus the radial distances to all the target point images can be measured on the photograph from the point of

autocollimation. These are called the measured radial distances. But at this stage since we know a value for the focal length (EFL) the theoretical radial distances to all the target point images can be determined using the relation

$$\text{Theoretical radial distance} = \text{EFL} \times \tan\theta$$

where 'θ' is the corresponding angle. Thus two radial distances are obtained for a point; measured radial distance and the theoretical radial distance. If the lens is completely distortion free then these values will be the same. But since no lens is completely distortion free these two will not be equal. The difference between the measured and the theoretical radial distances is called the Radial lens distortion.

$$\therefore \begin{array}{c}\text{Radial lens}\\ \text{distortion}\end{array} = \begin{array}{c}\text{Measured radial}\\ \text{distance}\end{array} - \begin{array}{c}\text{Theoretical radial}\\ \text{distance.}\end{array}$$

Radial lens distortion may be positive or negative depending upon the numerical values of the measured and theoretical radial distances.

From the above discussion it is clear that the radial lens distortion values change with the focal length used. Different focal lengths give different radial lens distortion characteristics.

III-3.2.3 CALIBRATED FOCAL LENGTH:

This is the Focal length which produces an overall mean distribution of the radial lens distortion. This can be obtained by equating the maximum positive radial lens distortion to maximum negative radial lens distortion.

For example if the maximum positive distortion occurs at a measured radial distance r_1 and at an angle θ_1 and the maximum negative distortion occurs at a measured radial distance r_2 at a corresponding angle θ_2, then CFL can be determined by equating these two in the following manner:

$$r_1 - \text{CFL} \tan \theta_1 + r_2 - \text{CFL} \tan \theta_2 = 0$$

Radial lens distortion based upon CFL can thus be determined as in III-3.2.2. These distortions can be plotted against the radial distance to give the Radial lens distortion curve which is a graphical representation of the distortion characteristics of the camera lens.

On the other hand a polynomial of the form

$$dr = k_1 r^3 + k_2 r^5 + k_3 r^7 + \ldots\ldots + k_n r^{2n+1}$$

can be fitted to the above graphical representation, where

dr = Radial lens distortion at any radial distance r

k_1, k_2, k_3 = constants

$r = (x^2 + y^2)^{1/2}$

x, y = measured photo-coordinates of the image point.

Investigations have shown that for the relatively simple lenses often used in Non-metric cameras k_1 is the only significant coefficient (Karara et al, 1974). Thus

$$dr = k_1 r^3$$

k_1 is called the Radial lens distortion coefficient. Knowing the value of k_1, thus the radial distortion at any point can be determined. k_1 is determined using least squares method to get more accurate results, even though it is single valued. This is quite evident from the following,

we have the relation

$$dr = k_1 r^3$$

let $r^3 = R$,

then

$$dr = k_1 R$$

Therefore we get

$$v_1 = k_1 R_1 - dr_1$$

$$v_2 = k_1 R_2 - dr_2$$

$$v_3 = k_1 R_3 - dr_3$$

$$\vdots$$

where $v_1, v_2 \ldots\ldots$ are the residuals

$$\therefore \Sigma (v_i)^2 = \Sigma (k_1 R_i - dr_i)^2 = F(k)$$

In least square method since the sum of the squares of the residuals are minimized we get

$$\frac{dF(k)}{dk} = 0$$

$$\therefore \quad \frac{dF(k)}{dk} = \Sigma\, 2(k\, R_i - dr_i)R_i = 0$$

$$2k\, \Sigma\, R_i^2 - 2\Sigma\, R_i\, dr_i$$

$$\therefore \quad k = \frac{\Sigma\, R_i\, dr_i}{\Sigma\, R_i^2}$$

The arithmetic mean and other means may give different values. But the least squares minimal solution gives more accurate results.

III-3.2.4 LOCATION OF PRINCIPAL POINT

The improper centering of the lens produces the bent-axis effect the result of which is to displace the principal point away from the point of autocollimation. Also this defect produces radial lens distortions asymmetrical about the point of autocollimation. Thus this provides a method for determining the principal point location, by determining the principal point shift away from the point of autocollimation, by considering the asymmetry of the distortions around the point of autocollimation (Karren, 1968). Thus the position of the principal point can be obtained by balancing the radial lens distortions around the point of autocollimation.

This method has been used in the present study. The method is explained in detail in the paragraph IV-2.4.1.6.

III-3.2.5 FIDUCIAL MARKS AND FIDUCIAL AXES SYSTEM:

Non-metric cameras lack Fiducial marks. One method is to introduce Fiducial marks in the form of glass plate at the back of the camera. The other way is to use methods such as Direct linear Transformation (Karara, 1974) which does not require the Fiducial marks. First method has not been tried since it can be done only by the manufacturer if the camera is not to be spoiled and the second method for the want of software. In the present case the sharp corners of the format themselves are considered as the Fiducial marks (Goodrich, 1982).

To obtain the Fiducial axes system with reference to which the co-ordinates of the image points can be measured, the following procedure has been adopted (Fig. IV-2 and paragraph IV-2.3.).

1. The co-ordinates of the left bottom corner, right bottom corner and left top corner are measured in the comparator/digitizer co-ordinate system (Fig. IV-3).
2. Knowing these co-ordinates the lengths of the bottom edge and the left edge can be determined as explained in paragraph IV-2.3.

3. Fiducial axes system for all further measurements is thus obtained as shown in Fig. IV-2. However least square solution using four corners gives better results.

III-3.2.6 ANGLE OF INTERSECTION OF FIDUCIAL AXES:

In the above case (Fig. IV-2) the Fiducial lines are constrained to be parallel to the bottom edge and left edges of the format. If these edges are not perpendicular to each other then the Fiducial lines will also not be perpendicular.

The perpendicularity of the Fiducial axes system may be ascertained by determining the mutual perpendicularity of the left and bottom edges. The following procedure is adopted:

1. From the comparator/Digitizer measurements the x and y coordinates of the left bottom corner, right bottom corner are known in the comparator/Digitizer coordinate system.

2. Thus knowing the x and y co-ordinates of the bottom edge (e.g. x', y' and x'', y'') a straight line equation may be found for the bottom edge by using the relation

$$y-y' = \frac{y'' - y'}{x'' - x'} (x - x')$$

3. Similarly another straight line equation may be found for the left edge.

4. From the above two equations two slopes are obtained (say m_1 and m_2).

5. Knowing the slopes of the two straight lines the angle between them (α) can be determined using the relation

$$\alpha = \tan^{-1} \left[\frac{m_1 - m_2}{1 + m_1 m_2} \right]$$

This angle should be $90° \pm 1'$.

An illustration is given in Appendix C.

Since the same camera and the same enlarger have been used throughout the work this illustration will be sufficient. Also the format size and shape do not change with exposure to exposure.

III-4 CAMERA-ENLARGER SYSTEM CALIBRATION:

As has been pointed out earlier the main intention of the work is to evaluate the Non-metric camera-Digitizer combination for close range photogrammetric work. Measurements cannot be made on the 35 mm film negative since the big size of the cursor (250 microns) obliterates the image point on the 35 mm negative. Hence to facilitate measurements with the digitizer the 35 mm film negatives were enlarged by 4.66 times using a photographic enlarger.

Although a digitizer is used primarily for the measurement of points, lines and areas from map data, it can also be used to measure points on the enlarged photographs to sufficien precision and accuracy for analytical adjustment. The precision

at the negative scale can be computed by dividing the precision (i.e. 250 microns) by the enlargement ratio (4.66). Thus it amounts to making measurements on the negative with a precision of 54 microns which is quite comparable to other photogrammetric machines (Welch et al, 1983).

During enlargement the film negative does not deform because it is sandwitched between two glass plates which are held tight together with the help of spring loaded clips in the negative carrier. Also sufficient care is taken to see that the negative plane in the enlarger is parallel to the paper print.

Thus the calibration gives the calibrated focal length, Radial lens distortion characteristics and the principal point location for the Non-metric camera-enlarger system.

III-5 TRANSFORMATION OF COMPARATOR/DIGITIZER CO-ORDINATES INTO PHOTO CO-ORDINATES:

Knowing the principal point location and hence the photo co-ordinate system the comparator/Digitizer co-ordinates can be transformed into photo-coordinates which can be used in photogrammetric analytical adjustments. For this purpose a conformal transformation has been used,

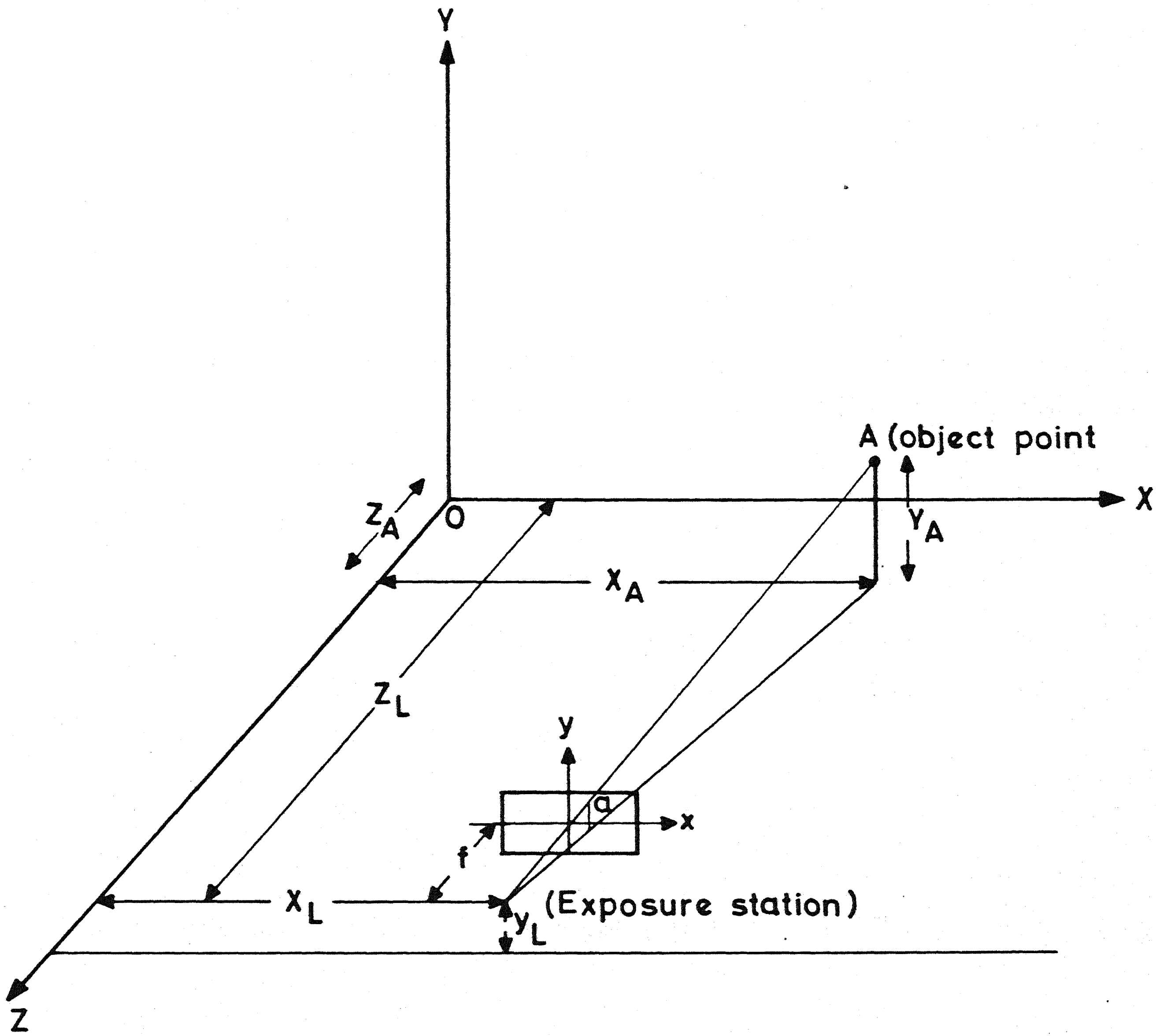


FIG. III.1 OBJECT SPACE COORDINATE SYSTEM.

the details of which are given in the paragraph IV-2.3.

III-6 TRANSFORMATION OF PHOTO-COORDINATES INTO OBJECT SPACE COORDINATES:

For this purpose the Least Squares Bundle Adjustment has been used. A brief description of the method is given in the pragraph V-2.4. For more details Appendix C may be referred. Check point discrepancies indicate the precision of the transformation capability of the Non-metric camera Digitizer system. In addition the Bundle Adjustment method gives lot of other information about the standard error, variance and co-variance etc. However for the evaluation of the camera-Digitizer system the check point discrepancies provide sufficient information.

A simple chair has been considered to provide a three dimensional test field over the entire depth of field of photography. Similarly a simple pot has been chosen for mapping using contours.

CAMERA-ENLARGER SYSTEM CALIBRATION

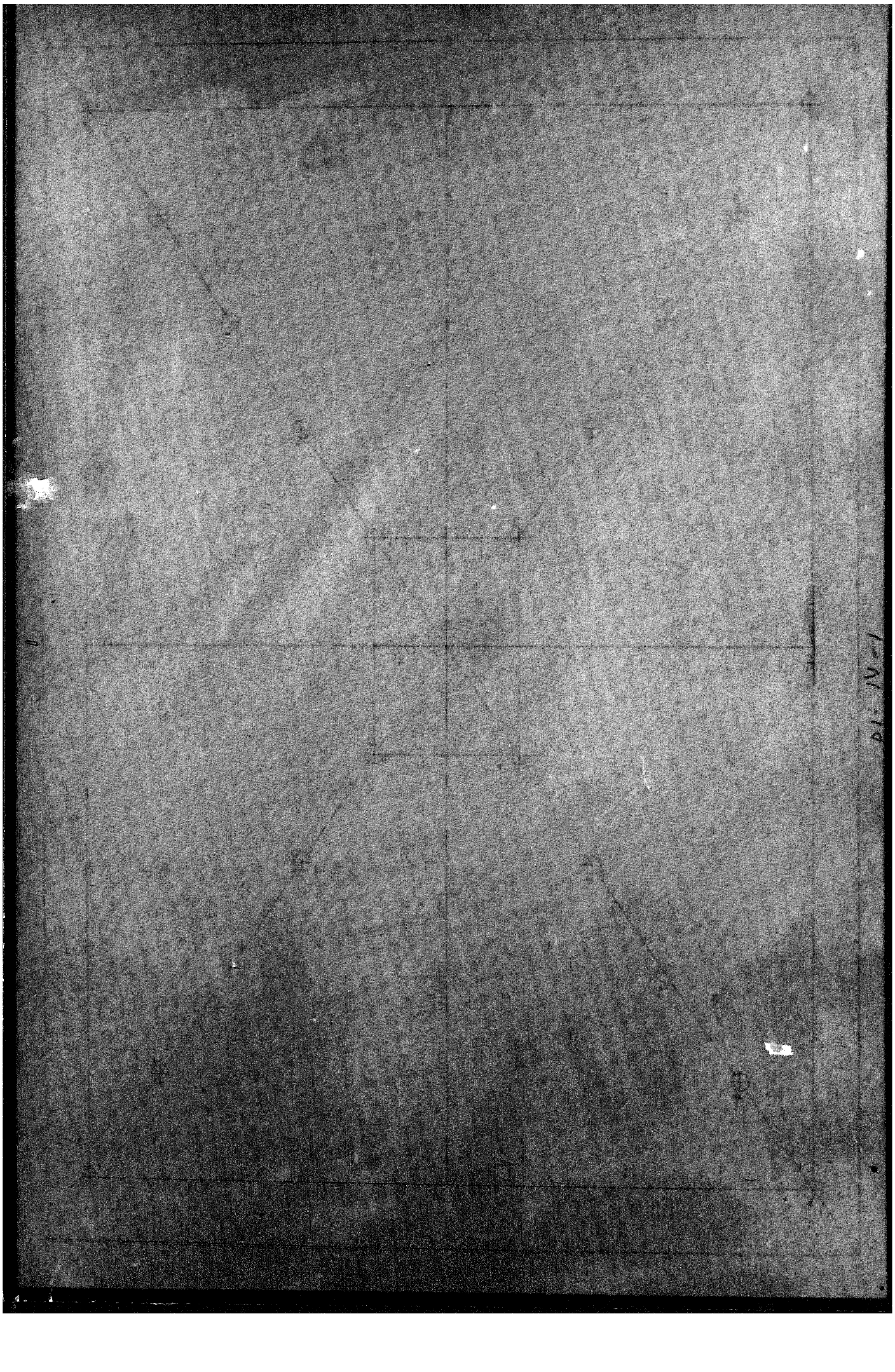
IV-1 INTRODUCTION

As in any photogrammetric system the main component of this work also is the calibration of the optical system consisting of camera and the enlarger. As has been already pointed out non-metric cameras such as the one used here are manufactured for picture quality and will have variable image distance. Also the lens distortions and the principal point off-sets are usually high. Thus the first phase of accuracy analysis is the determination of the Calibrated Focal Length, Principal point offsets and the Radial Lens Distortion characteristics. In order to achieve accurate measurements in the third dimension it is necessary that the inner orientation parameters of a camera must be exactly known.

IV-2 PROCEDURE ADOPTED FOR CALIBRATION

IV-2.1 PHOTOGRAPHY PHASE:

A target field was prepared on a Koda-Trace paper consisting of 1 cm. diameter circles with a cross in the middle and crossing the photo format diagonally. A one second accuracy theodolite was placed in front of a plane wall exactly at 2.0 meters from the wall. The Koda-Trace paper with the target marks was fixed on the wall


Pl. IV-1

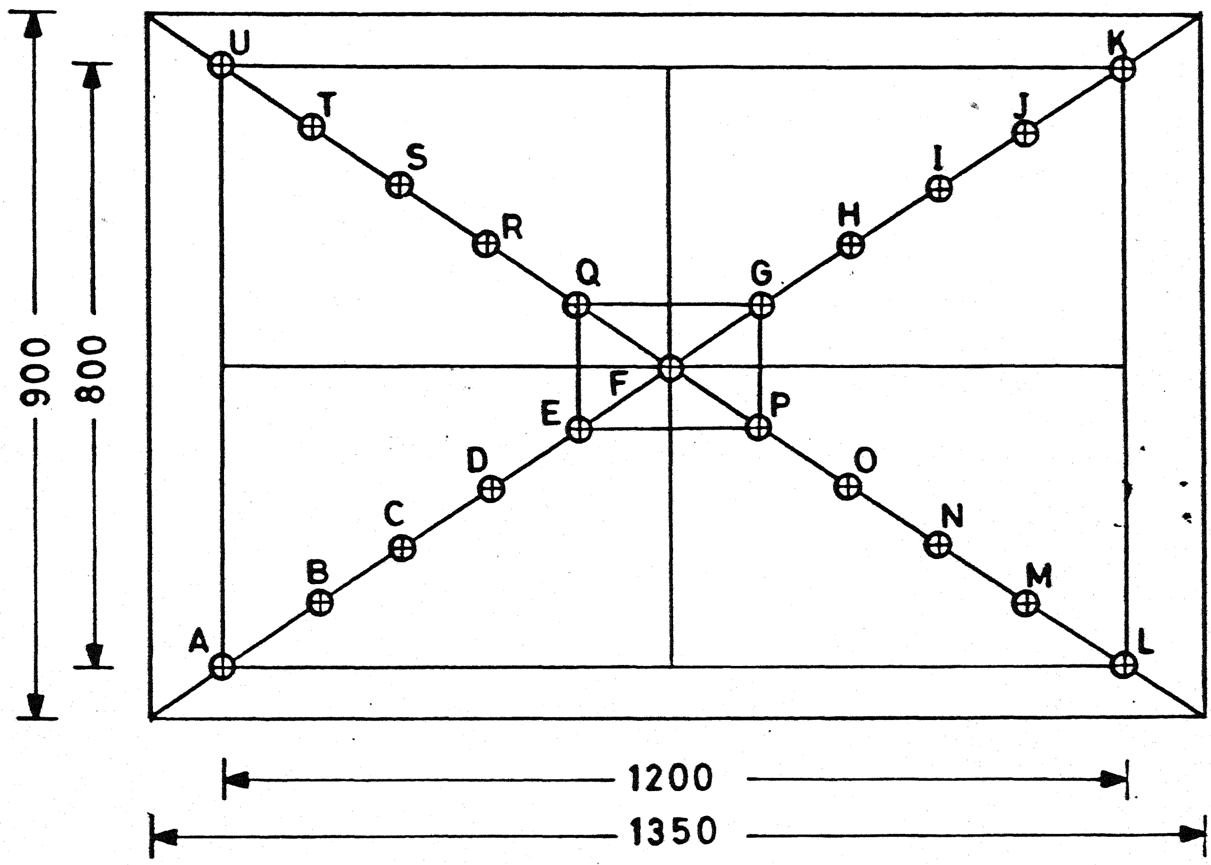


FIG. IV-1 TARGET FIELD USED FOR CAMERA CALIBRATION

All dimensions are in mm.

such that the central target mark exactly coincided with the intersection of the cross-wires of the theodolite, which had been precisely levelled and set to use as a level. With the help of the theodolite the target field was properly shifted and oriented such that the horizontal lines were truly horizontal and the vertical lines truly vertical (Plate IV-1 and Fig. IV-1). With reference to the central target mark the angles to the other target marks were measured precisely.

The theodolite was removed and in its place the camera was placed so that the central target mark was exactly at the centre of the view finder. In this position the target marks crossed the format diagonally. The camera was levelled by placing a bubble tube (spirit level) on the top of the camera. Since the photography was indoors a Flash was used during exposure with a stop number of 11 and a shutter speed of 1/60 of a second. The entire length of the film was exposed with a view to monitor any changes from exposure to exposure at different portions of the film.

IV-2.2 MEASUREMENT PHASE

The second step in the calibration consisted in measuring the coordinates of the target point images on the exposed calibration photographs. This was done in three steps.

1. Measurement on the enlarged and projection printed photographs using Tectronix Tablet.Digitizer with a pixel size of 500 µ and a cursor size of 250 µ.

2. Measurement on the enlarged and projection printed paper prints using the plotting table of Wild Autograph A-8 as a coordinato-graph. This had a least count of 10 microns.

3. Measurement on 35 mm film negative with a Zeiss Jena 1818A stereo comparator, with a least count of 20 microns.

Measurements on enlarged paper prints were made since the main object of the thesis is to evaluate the system consisting of a non-metric camera and a digitizer. Enlarging the photographs was necessary as otherwise the big size of the cursor in the case of Digitizer would obliterate the image on 35 mm negative thus making impossible the measurements on a 35 mm film negative with the digitizer.

IV-2.2.1 MEASUREMENT ON ENLARGED PAPER PRINTS - DIGITIZER

The Digitizer gives the coordinates of a point, in the digital form, displayed on the console. DOGS (Drafting of Graphic Systems) package was used to measure the coordinates. The paper print was firmly fixed to the Tablet by means of adhesive tape, and using the four button cursor in the measuring

mode the coordinates were recorded. Two pointings were made on each target point and the four corners.

IV-2.2.2 MEASUREMENT ON ENLARGED PAPER PRINTS - AUTOGRAPH A-8

The paper print was placed on the plotting table of the Wild Autograph A-8 and properly fixed using adhesive tape and by placing weights at the corners. Two pointings were made on each of the target point and four corners.

All paper prints used in the above two cases and throughout this work were projection printed using Belvish photographic enlarger. Care was taken during enlarging to make the plane of the negative parallel to the plane of the paper print. The average enlargement ratio used throughout this work is 4.66.

IV-2.2.3 MEASUREMENT ON 35 mm NEGATIVE

The 35 mm film negative was placed approximately at the centre of the film carrier of the stereo comparator. The film carrier was rotated about the vertical axis so as to make the edges of the film format approximately parallel to the comparator coordinate system. Using the comparator monoscopically two pointings were made here also on each of the target point image and the four corners of the format.

IV-2.3 REDUCTION OF MEASURED COORDINATES TO PHOTO COORDINATE SYSTEM

At this stage the coordinates of all the target points and the corners of the format on both 35 mm film negative and on the Enlarged paper prints, are known in the comparator/ Digitizer coordinate syst em. To be used in analytical photo-grammetric methods these coordinates are to be transformed into the coordinates in photo-coordinate system. Fiducial axes system is the rectangular coordinate system with the Fiducial axes as the coordinate axes and the intersection of these fiducial axes as the fiducial origin. But the non-metric camera lacks the Fiducial marks. One method is to introduce the fiducial marks in the form of glass plate at the back of the camera, which is easily not possible. However this was not tried in the present study as it would have defeated the very purpose of investigating the utility of inexpensive methods by the use of amateaur cameras in photogrammetric measurements. Instead the corners of the format themselves were considered as the fiducial marks

A two dimensional conformal coordinate transformation transforms the coordinates of one rectangular coordinate system into the other without affecting the geometry. For this purpose the coordinates of atleast two points must be known in both the coordinate systems. The following procedure was adopted to transform all the comparator/digitizer coordinates into the Fiducial axes system.

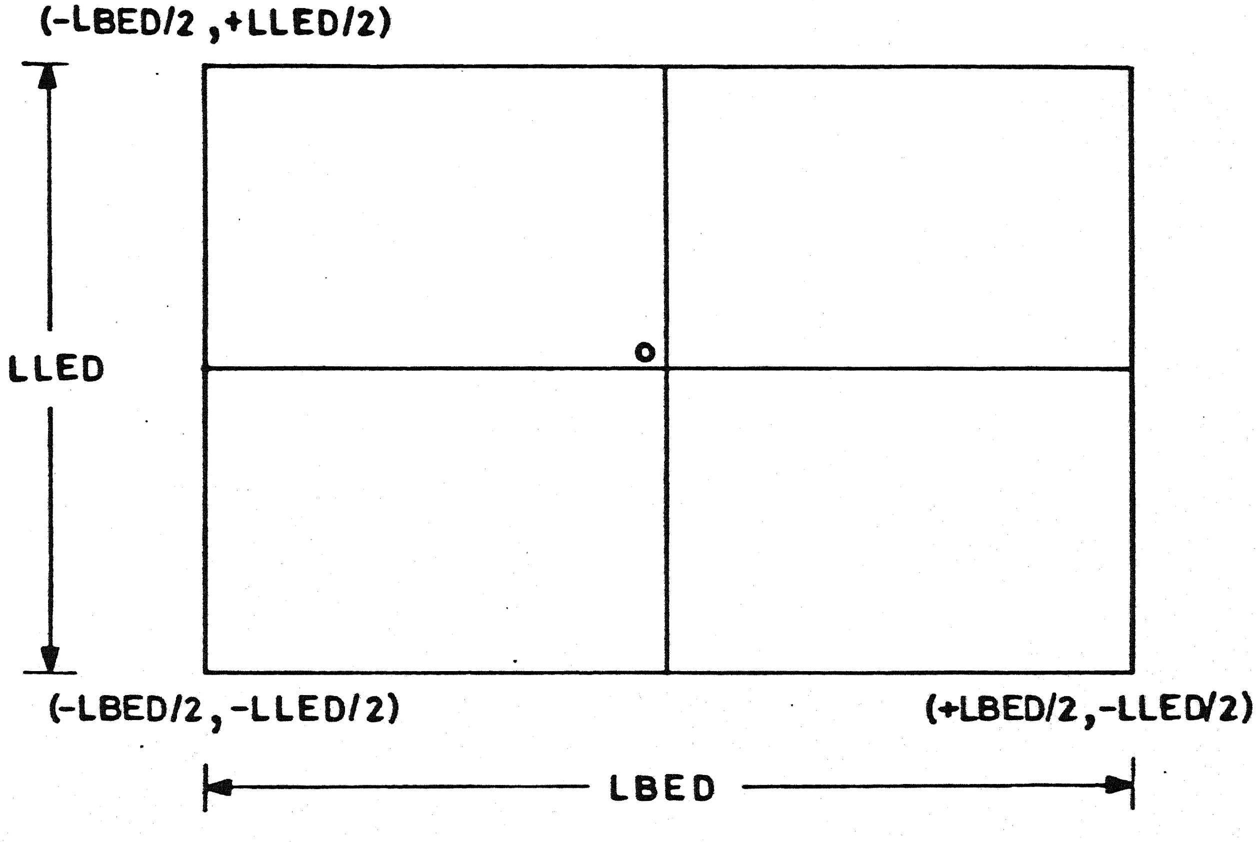


FIG.IV-2 FIDUCIAL AXES SYSTEM

With reference to Fig. IV-2

LBC(X), LBC(Y) = are the X and Y coordinates of the left bottom corner in the comparator coordinate system.

LTC(X), LTC(Y) = are the X and Y coordinates of the left top corner in the comparator coordinate system.

RBC(X), RBC(Y) = are the X and Y coordinates of the right bottom corner in the comparator coordinate system.

Then

$$LBED = [(RBC(X) - LBC(X))^2 + (RBC(Y) - LBC(Y))^2]^{1/2}$$

$$LLED = [(LBC(X) - LTC(X))^2 + (LBC(Y) - LTC(Y))^2]^{1/2}$$

where

LBED and LLED are the lengths of the bottom edge and the left edge of the format respectively.

The bisectors of these lengths were considered as the Fiducial axes and their intersection at the centre of the photograph as the origin. With this system as the Fiducial axes system the image-coordinates of the corners of the format, now serving as the Fiducial marks, were found out as follows:

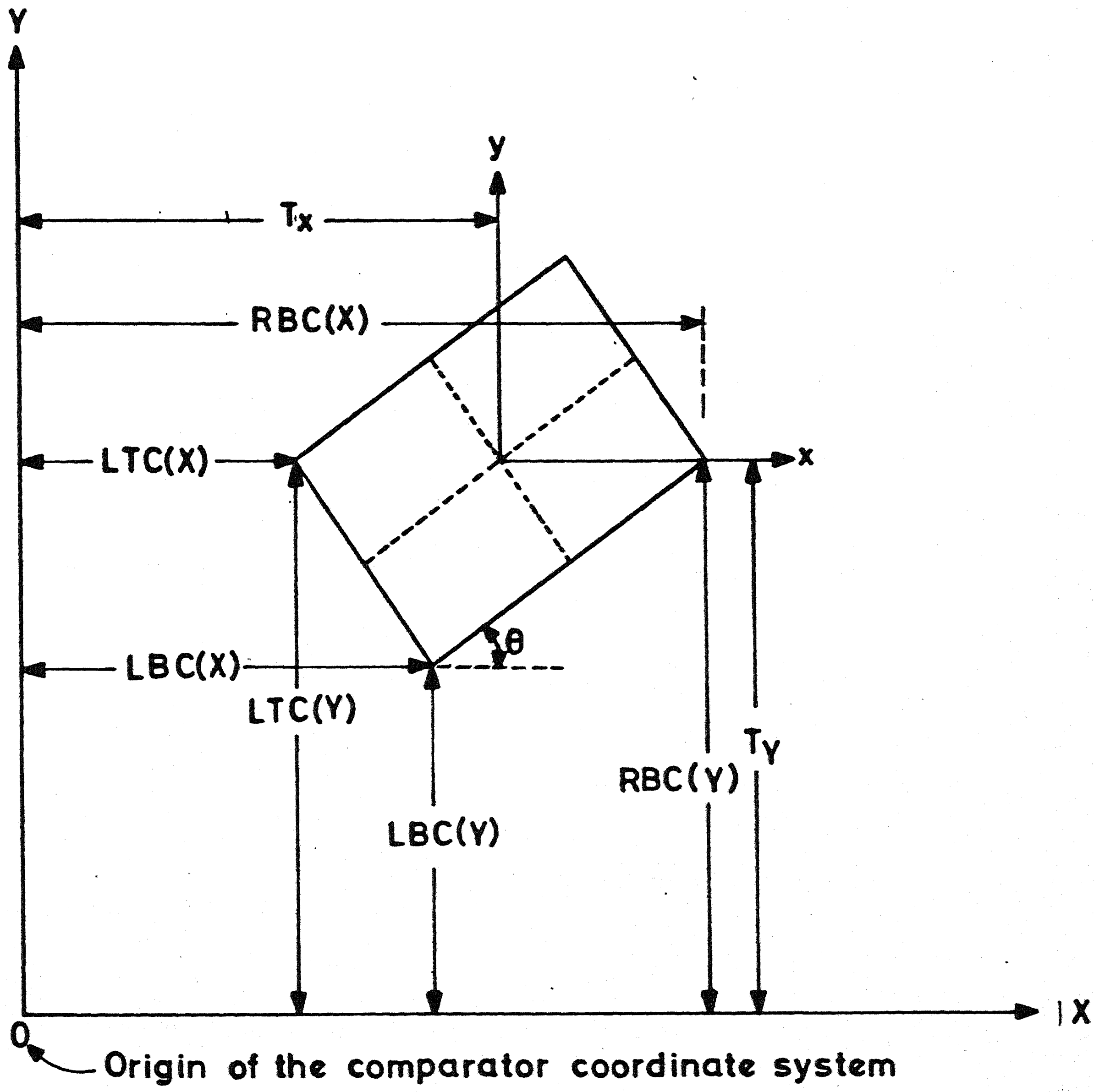


FIG. IV-3 TWO DIMENSIONAL CONFORMAL COORDINATE TRANSFORMATION.

image-coordinates of the left bottom corner = -LBED/2, -LLED/2

image-coordinates of the right bottom corner = +LBED/2, -LLED/2

The Fiducial axes system is thus constrained to be parallel to the left and bottom edges of the format.

Thus at this stage knowing the coordinates of the corners both in comparator/digitizer coordinate system and the Fiducial axes system transformation was possible and was applied in the following steps (Fig. IV-3):

1. $\theta = \tan^{-1} \dfrac{RBC(Y) - LBC(Y)}{RBC(X) - LBC(X)}$

2. $x_p = x_c \cos\theta - y_c \sin\theta$ Rotation

$y_p = x_c \sin\theta + y_c \cos\theta$

3. $T_x = -LBED/2 - LBC(X)$

$T_y = -LLED/2 - LBC(Y)$

Translation

4. $x_{pc} = x_p + T_x$

$y_{pc} = y_p + T_y$

where

θ = angle of rotation

x_p, y_p = coordinates of the points in the tilt corrected axis system

y_x, y_c = measured comparator/digitizer coordinates

x_{pc}, y_{pc} = transformed coordinates of the points in the Fiducial axes system

T_x, T_y = translation in the x and y directions respectively.

A computer program given in Appendix B transformed all the comparator/digitizer coordinates into coordinates in Fiducial axes system.

IV-2.4 COMPUTATIONS

Measurements were made on three enlarged paper prints with the digitizer and the Autograph-A8 and on three 35 mm film negative with the comparator at different positions along the length of the film. Measurements have been thus made on 5th frame, 18th frame and the 30th frame. However for the want of time and space, only the details of the middle frame (i.e. the 18th frame) have been illustrated below. The results of the other frames are summarised at the end for comparison.

IV-2.4.1 ENLARGED PHOTOGRAPHS - WITH DIGITIZER (Frame - 18)

IV-2.4.1.1 TO DETERMINE EQUIVALENT FOCAL LENGTH (EFL)

Average angle to the points P, Q, G, E = 4.0930 degrees

Average measured distance = 16.579 mm

$\therefore$ Equivalent Focal length (EFL) $= \dfrac{16.579}{\tan(4.0930)} = 231.686$ mm

IV-2.4.1.2 RADIAL LENS DISTORTION BASED UPON EFL

Angle (θ) deg.	Measured radial distance (r) (mm)	EFL tan θ (mm)	Radial distortion (dr) (mm)
4.0930	16.579	16.579	0.000
8.1355	33.178	33.120	+0.058
12.1033	49.485	49.683	−0.198
15.9836	65.888	66.364	−0.476
19.6990	82.037	82.951	−0.914

IV-2.4.1.3 CALIBRATED FOCAL LENGTH (CFL)

Calibrated Focal length of a lens is a focal length which produces an overall mean distribution of Radial distortion, and is selected such that maximum positive Radial distortion is equal to the maximum negative radial distortion. In the above case, maximum positive radial distortion is +0.058 mm and occurs at a measured distance of 33.178 mm and an angle of 8.1355 degrees. Maximum negative radial distortion is −0.914 mm and occurs at a measured distance of 82.037 mm and an angle of 19.6990 degrees.

Equating these two:

$$33.178 - CFL \tan(8.1355) + 82.037 - CFL \tan(19.6990) = 0$$

Calibrated Focal length (CFL) = 229.978 mm.

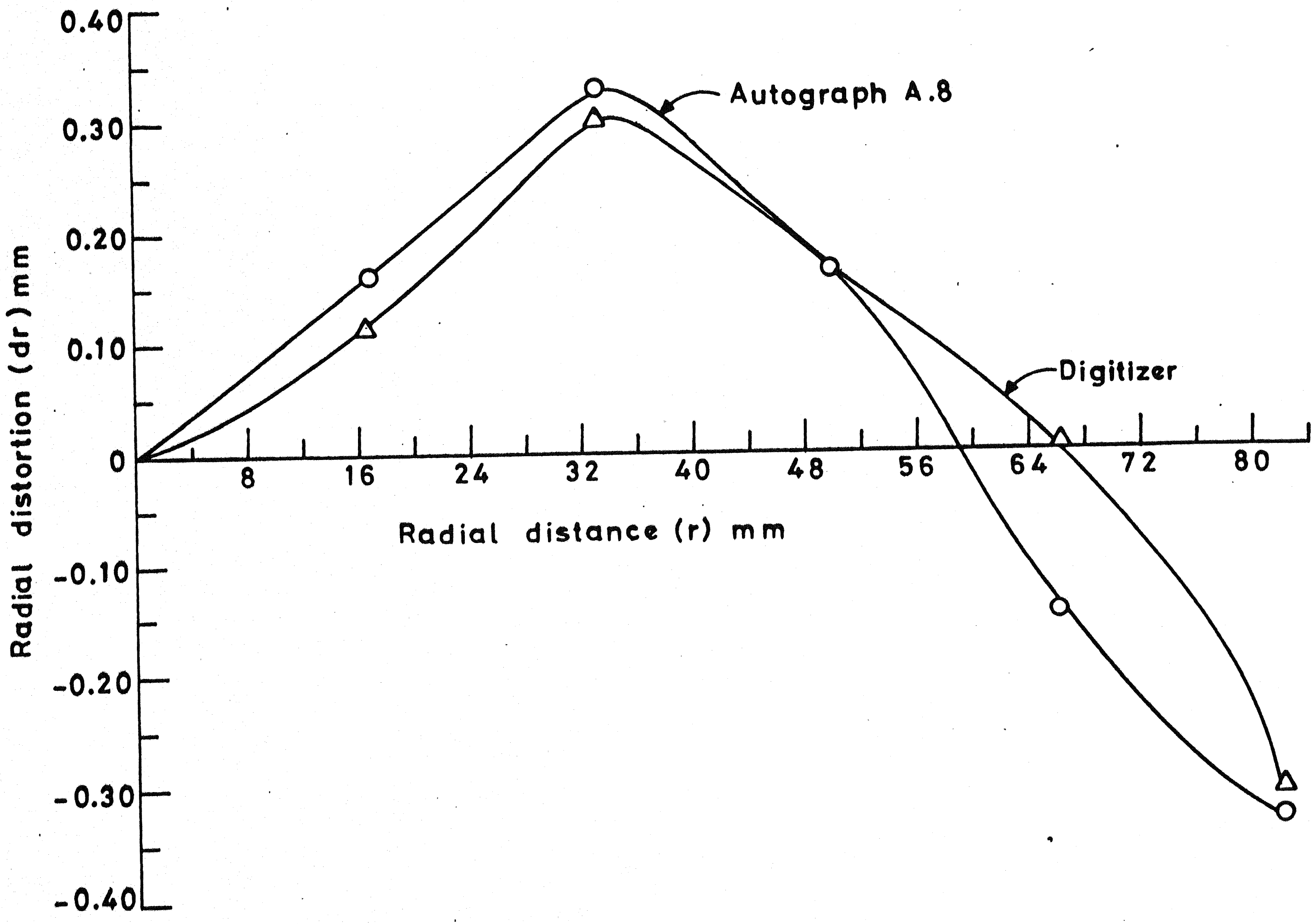


FIG. IV-4 RADIAL LENS DISTORTION CURVE ENLARGED PHOTOGRAPHS FRAME-18. (based upon CFL

IV-2.4.1.4 RADIAL LENS DISTORTION BASED UPON CFL

Angle (θ) deg.	Measured radial distance (r) (mm)	CFL tan θ (mm)	Radial distortion (dr) (mm)
4.0930	16.579	16.457	+0.122
8.1355	33.179	32.877	+0.302
12.1033	49.485	49.317	+0.168
15.9836	65.888	65.874	+0.014
19.6990	82.037	82.339	-0.302

Radial lens distortion curve is shown in Fig. IV-4.

IV-2.4.1.5 RADIAL LENS DISTORTION COEFFICIENT

The above radial distortion curve can be expressed mathematically in the form of a polynomial of the form

$$dr = k_1 r^3 + k_2 r^5 + k_3 r^7 + \ldots\ldots$$

where

dr = radial distortion at any radial distance r

$k_1, k_2, k_3, ..$ = constants

However in the present work only the cubic term is considered (Karara, 1974)

i.e. $dr = k_1 r^3$.

Thus for the above data the Radial lens distortion coefficient was determined, so that at any radial distance the correction could be applied.

$$K_1 = -0.3248 \times 10^{-6}.$$

Corrections can be applied in the following manner:

$$dx = k_1 \frac{x}{r}, \quad dy = k_1 \frac{y}{r}$$

where,

x, y = photo-coordinates of a point

r = radial distance = $(x^2 + y^2)^{1/2}$

k_1 = radial lens distortion coefficient as determined above.

These corrections are algebraically added to the measured photo-coordinates of the points to get the corrected coordinates.

IV-2.4.1.6 PRINCIPAL POINT LOCATION

If the measured distances and hence the distortions are equal at the equal angle points then the radial distortion is said to be symmetrical. If not the principal point will not be exactly at the central target mark. This offset in x and y directions is called principal point offset. In non-metric cameras usually these offsets will be large.

In the present study the target points are not at equal angles. Hence a different procedure had to be adopted

to determine the principal point offsets. The following procedure was adopted:

1. Radial lens distortion based upon the calibrated focal length and hence the radial lens distortion coefficients were determined for each of the diagonals separately in exactly the same manner as explained in paragraphs IV - 2.4.1.1 - IV - 2.4.1.6.

2. For each diagonal the values of EFL, CFL and k_1 varied. But the value of k_1 for each diagonal represents the overall mean distribution of the radial lens distortion along that diagonal.

3. Considering a known and common measured radial distance along each of the diagonals the radial lens distortion along each diagonal was determined using the relation $dr = k_1 r^3$.

4. Since the value of k_1 differed for each diagonal the value of the radial lens distortion dr also varied for each diagonal.

5. Knowing the difference in dr along the diagonals the position of the principal point was determined by balancing these distortions.

Thus for example the following are the values of the Radial distortion coefficients and considering 16.579 mm as the measured distance the following table gives the values of Radial lens distortion along each of the four diagonals.

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Acc. No. A 104103

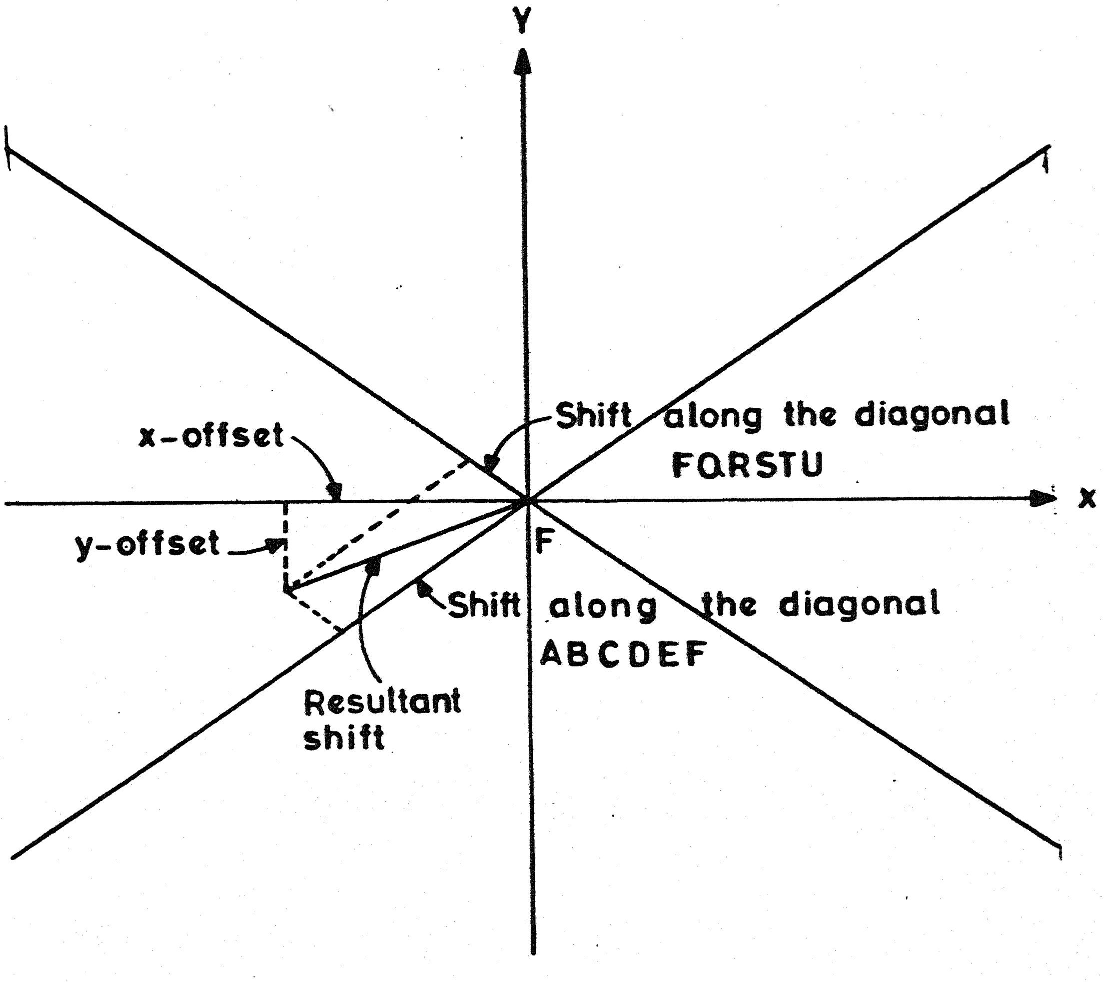

FIG. IV-6 DETAILS AT THE CENTRAL TARGET POINT IN DETERMINING THE PRINCIPAL POINT OFFSET

Diagonal	Radial lens distortion coefficient, k_1	Radial lens distortion dr (mm)
FGHIJK	-0.8371×10^{-6}	-0.00381
FQRSTU	-0.2157×10^{-6}	-0.000983
FEDCBA	$+0.8432 \times 10^{-7}$	+0.000384
FPONML	-0.2351×10^{-6}	-0.00107

With reference to Fig. IV-6.

Radial lens distortion along the diagonal

FGHIJK = -0.00381 mm

Radial lens distortion along the diagonal

FEDCBA = +0.000384 mm.

Thus along these diagonals about the point 'F' which is the central target mark the distortions are not symmetrical. To balance these errors and make them symmetrical about the point 'F', a quantity 0.00171 mm must be deducted from 0.00381 mm and the same quantity is to be added to 0.000384 mm. This yields a radial distortion of 0.002097 on both the sides of the point 'F' along the diagonals under study, which is symmetrical about 'F'. Hence the position of the principal point along these diagonals occurs not at the point 'F' but a little shifted towards A along the diagonal FEDCBA by an amount equal to 0.0017 mm. Same procedure was adopted along the diagonals FQRSTU and FPONML and the shift was found to be

0.0004 mm towards U along the diagonal FQRSTU. Parallellogram law gave the resultant of these two shifts which was then transformed to give components in the X and Y directions. Thus the principal point offset determined as above worked out to

$$dx = x \text{ direction} = -0.002 \text{ mm} \;:\; x_o = -0.002 \text{ mm}$$

$$dy = y \text{ direction} = -0.0005 \text{ mm} \;:\; y_o = -0.0005 \text{ mm}$$

The same procedure was adopted in the other two cases also.

IV-2.4.2 ENLARGED PHOTOGRAPH - AUTOGRAPH A-8

IV-2.4.2.1 TO DETERMINE EQUIVALENT FOCAL LENGTH

Average angle to the points P,Q,G,E = 4.0930 deg.

Average measured distance = 16.651 mm

Equivalent Focal length (EFL) $= \dfrac{16.651}{\tan(4.0930)} = 232.692$ mm

IV-2.4.2.2 RADIAL LENS DISTORTION BASED UPON EFL

Angle(θ) deg.	Measured radial distance (r) (mm)	EFL tanθ (mm)	Radial distortion dr (mm)
4.0930	16.651	16.651	0.00
8.1355	33.291	33.264	+0.027
12.1355	49.613	49.899	-0.286
15.9836	65.898	66.651	-0.753
19.6990	82.224	83.311	-1.087

IV-2.4.2.3 CALIBRATED FOCAL LENGTH (CFL)

$$33.291 - \text{CFL} \tan(8.1355) + 82.224 - \text{CFL} \tan(19.6990) = 0$$

$$\text{CFL} = 230.575 \text{ mm}$$

IV-2.4.2.4 RADIAL LENS DISTORTION BASED UPON CFL

Angle θ deg.	Measured radial distance (r) (mm)	CFL tanθ (mm)	Radial distortion dr (mm)
4.0930	16.651	16.500	+0.151
8.1355	33.291	32.962	+0.329
12.1033	49.613	49.445	+0.168
15.9836	65.898	66.045	-0.147
19.6990	82.224	82.553	-0.329

Radial lens distortion curve is shown in Fig. IV-4.

IV-2.4.2.5 RADIAL LENS DISTORTION COEFFICIENT

$$k_1 = 0.4429 \times 10^{-6}$$

IV-2.4.2.6 PRINCIPAL POINT OFFSETS

dx (mm) = -0.0019 : x_o = -0.0019 mm

dy (mm) = -0.0006. : y_o = -0.0006 mm.

IV-2.4.3 35 mm FILM NEGATIVE - COMPARATOR

IV-2.4.3.1 TO DETERMINE EQUIVALENT FOCAL LENGTH (EFL)

Average angle to the points P,Q,G,E = 4.0930 deg.

Average measured distance = 3.682 mm

Equivalent Focal length (EFL) $= \dfrac{3.682}{\tan(4.0930)} = 51.455$ mm

IV-2.4.3.2 RADIAL LENS DISTORTION BASED UPON EFL

Angle θ deg.	Measured radial distance (r) (mm)	EFL tanθ (mm)	Radial distortion (dr) (mm)
4.0930	3.682	3.682	0.00
8.1355	7.318	7.356	-0.038
12.1033	11.019	11.034	-0.015
15.9836	14.637	14.738	-0.101
19.6990	18.199	18.422	-0.223

IV-2.4.3.3 CALIBRATED FOCAL LENGTH (CFL)

CFL = 51.037 mm.

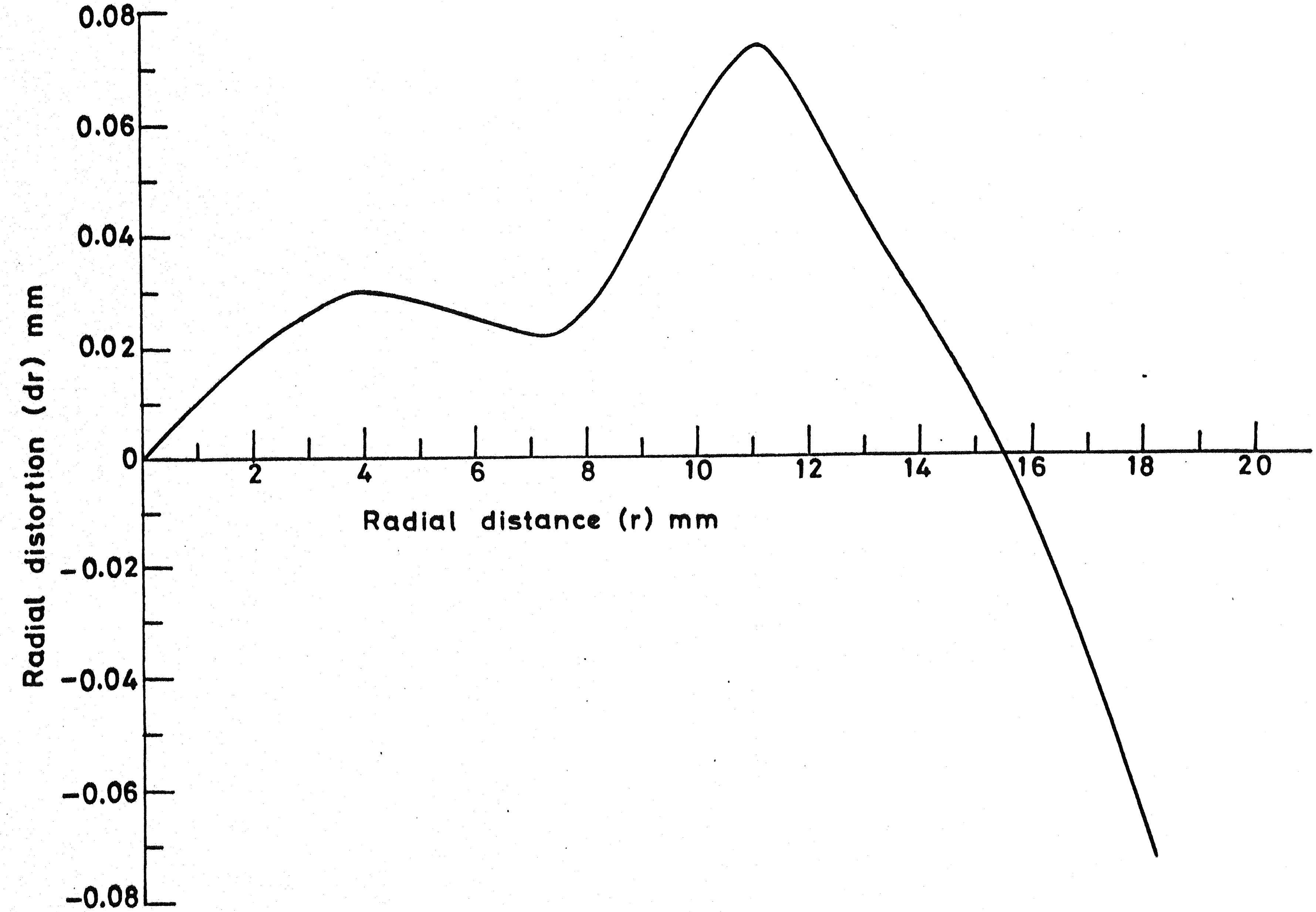

FIG. IV-5 RADIAL LENS DISTORTION CURVE 35mm FILM NEGATIVE (MEASUREMENT WITH COMPARATOR) FRAME-18.

IV-2.4.3.4 RADIAL LENS DISTORTION BASED UPON CFL

Angle θ deg.	Measured radial distance (r) (mm)	CFL tanθ (mm)	Radial distortion (dr) (mm)
4.0930	3.682	3.652	+0.030
8.1355	7.318	7.296	+0.022
12.1033	11.019	10.944	+0.075
15.9836	14.637	14.619	+0.018
19.6990	18.199	18.273	-0.075

Radial lens distortion curve is shown in Fig. IV-5.

IV-2.4.3.5 RADIAL LENS DISTORTION COEFFICIENT

$$k_1 = -0.5784 \times 10^{-5}$$

IV-2.4.3.6 PRINCIPAL POINT OFFSETS

dx (mm) = -0.00018 : x_o = -0.00018 mm

dy (mm) = -0.00042. : y_o = -0.00042 mm

IV-3 CALIBRATION RESULTS

Particulars	Exposure 5	Exposure 18	Exposure 30
CFL (mm)	229.9765	229.978	229.975
k_1	-0.3246×10^{-6}	-0.3248×10^{-6}	-0.3259×10^{-6}
Principal point offset			
dx(mm) (x_o)	-0.00291	-0.002	-0.0017
dy(mm) (y_o)	-0.0006	-0.0005	-0.0008

TABLE IV-3.1 CALIBRATION RESULTS : ENLARGED PHOTOGRAPHS - (DITIGIZER)

Particulars	Exposure 5	Exposure 18	Exposure 30
CFL (mm)	230.425	230.575	230.445
k_1	-0.4425×10^{-6}	-0.4349×10^{-6}	-0.4145×10^{-6}
Principal point offset			
dx (mm)(x_o)	-0.0031	-0.0019	-0.0017
dy (mm)(y_o)	-0.0048	-0.0006	-0.0009

TABLE - IV-3.2 CALIBRATION RESULTS : ENLARGED PHOTOGRAPHS (AUTOGRAPH A-8)

Particulars	Exposure 5	Exposure 18	Exposure 30
CFL (mm)	51.0378	51.0374	51.038
k_1	-0.5789×10^{-5}	-0.5784×10^{-5}	-0.5813×10^{-5}
Principal point offset			
dx(mm) (x_o)	-0.0003	-0.00018	-0.00011
dy(mm) (y_o)	-0.00024	-0.00042	-0.0005

TABLE - IV-3.3 CALIBRATION RESULTS: 35 mm NEGATIVE (COMPARATOR)

Table IV-3.1 through IV-3.3 show the calibration results for all the cases. In all further calculations which involve enlarged photographs measured upon the digitizer, the following values for the inner orientation parameters are considered:

Calibrated Focal Length (CFL) = 229.978 mm

Radial Lens Distortion Coefficient (k_1) = -0.3248×10^{-6}

Principal Point Offsets dx(mm) = (x_o) = -0.002

dy(mm) = (y_o) = -0.0005.

The results tabulated indicate the following:

1. The radial lens distortion characteristics and hence the other inner orientation parameters have been significantly influenced by the distortion characteristics of the enlarged lens. This is evident from

the fact that the inner orientation parameters in the case of enlarged photographs cannot be obtained just by multiplying the inner orientation parameters in the case of 35 mm film negative, by the enlargement ratio of 4.66. For example $51.037 \times 4.66 \neq 229.978$.

2. The results of calibration for different frames along the length of the film indicate that there is no considerable change in these parameters from frame to frame.

3. There is no significant difference in the values of the inner orientation parameters over those obtained by measurement on enlarged photographs using Digitizer and the plotting table attached to wild A-8 Autograph. Since the difference is very small and since in further work Digitizers are intended to be used, the calibration results obtained from enlarged photographs using Digitizer are considered, in all future computations.

direction. The camera base was kept at 57 cms. Camera stations were marked on the base line and the camera centred over the stations such that the centre of the knurled focussing ring was exactly above the marked camera station. Not much care was taken to level and orient the camera. But the camera was approximately oriented to avoid large deviations of the camera axis from the normal. The small rotations about the X, Y and Z axis could however be computed by again applying the similarity transformation of the photo-coordinates to the space coordinate system. This was done keeping in view that photography in most cases cannot be made exactly normal and also that thus the amateaur camera can be made use of in as simple a manner as taking exposures by a hand held camera. Exposures were made with a stop number of 11 and a shutter speed of 1/60 of a second.

V-2.2 MEASUREMENT ON PHOTOGRAPHS

The 35 mm film negatives were then enlarged and projection printed on bromide paper. The average enlargement ratio was 4.66. Same enlarger used in the case of calibration phase was used in this case also. Measurements were made on these enlarged photographs with the Tectronix Tablet Digitizer and with the plotting table of the Wild Autograph A-8 using it as a co-ordinatograph. In addition monoscopic measurements were also made on the 35 mm film negative with Zeiss Jena 1818A stereo-comparator.

V-2.3 TRANSFORMATION OF COMPARATOR/DIGITIZER COORDINATES INTO PHOTO-COORDINATES

The coordinates of the image points thus obtained in the arbitrary comparator/digitzer coordinate system were then transformed into the photo-coordinate system by applying two dimensional conformal coordinate transformation. A computer program was written for this purpose and in this program the results of the camera-enlarger calibration were also introduced so that the output from this program provided a data base for further computations, in the form of all-corrected photo-coordinates. A listing of the program with documentation is given in Appendix B.

V-2.4 TRANSFORMATION OF PHOTO-COORDINATES INTO OBJECT SPACE COORDINATES

Thus the above program provided a data base for further transformation of these photo-coordinates into the object space coordinates, which is the ultimate goal of any photogrammetric system. For this transformation a simultaneous Least Square Bundle Adjustment Method was used.

This Bundle Adjustment minimises the sum of the squares of weighted residuals for both photo and control measurements. The process involves formation of the following observation equations for each x and y measurement.

Observation Equations*

$$v_x = b_{11}\,(dw) + b_{12}(d\phi) + b_{13}\,(dk) - b_{14}\,(dX_L)$$
$$- b_{15}(dY_L) - b_{16}\,(dZ_L) - b_{14}(dX)$$
$$+ b_{15}\,(dY) + b_{16}\,(dZ) + J$$

$$v_y = b_{21}\,(dw) + b_{22}\,(d\phi) + b_{23}(dk) - b_{24}(dX_L)$$
$$- b_{25}\,(dX_L) - b_{26}(dZ_L) - b_{24}(dX)$$
$$+ b_{25}\,(dY) + b_{26}\,(dZ) + K$$

where

v_x, v_y - residual errors in measured x and y image coordinates.

$dw, d\phi, dk$ - corrections to the initial approximations for the orientation angles of the camera.

dX_L, dY_L, dZ_L - corrections to initial approximations for the exposers station coordinates.

dX, dY, dZ - corrections to initial values for the object space coordinates of the point.

Thus the input consists of the photo-coordinates of the stereopair, initial approximations of the object space coordinates and initial approximations of the exterior orientation elements of the camera. The control points are

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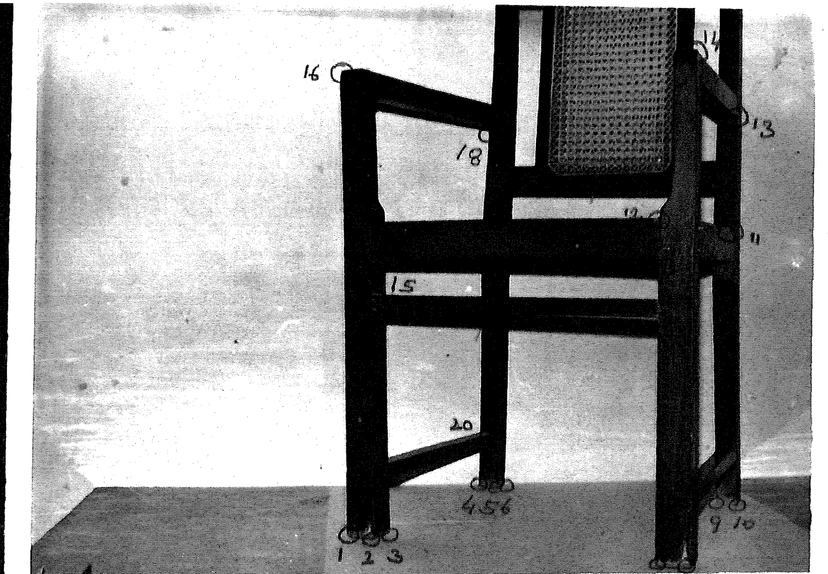
* For more details Appendix C may be referred.

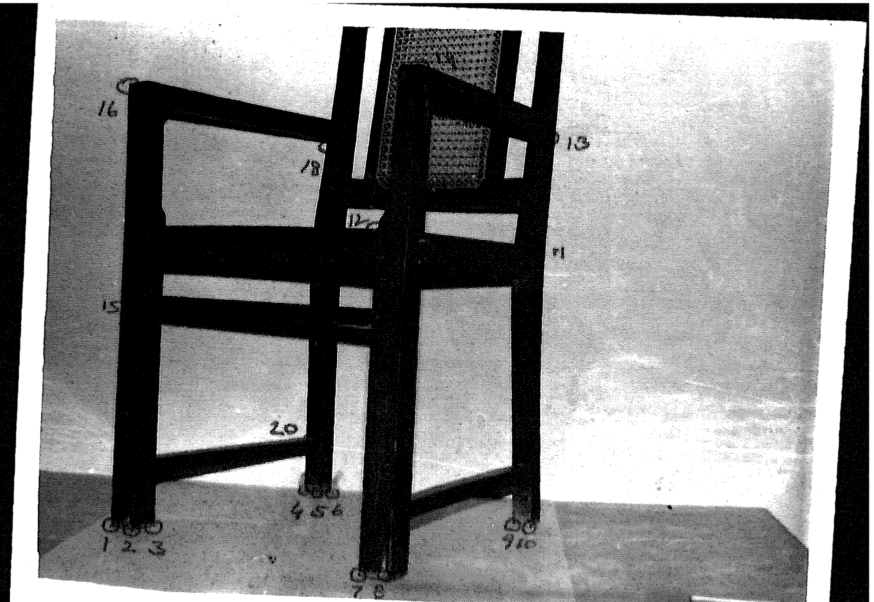
weighted down so that they do not change in the Bundle Adjustment Process. All the other points are considered as unknowns. Similarly all the exterior orientation parameters of the camera are considered as unknowns. Thus the method uses the collinearity and coplanarity conditions to determine the exterior orientation parameters first with reference to the provided control points and then these values are fed back to compute the position of other points in the object space.

Bundle Adjustment Program developed at Ohio State University to be used on IBM 360/370 has been modified and is available with complete documentation in the IIT-Kanpur DEC 10 system, as a software.

Bundle Adjustment Program is highly uneconomical and requires very fast and sophisticated computers. However it is a very highly accurate and rigorous analysis in photogrammetry. For more details the book on Photogrammetry by Dr. Rampal (Rampal K.K., 1982) may be referred.

The output from this Bundle Adjustment was a listing of the object space coordinates along with the residuals. For more details Appendix C may be referred. Input output data are given in Appendix B.


16
18
14
13
12
11
15
20
4 5 6
9 10
1 2 3
7 8
Pl V-1


16
13
18
12
11
15
20
4 5 6
1 2 3
9 10
7 8
Pl. V-2

V-3 EXPERIMENT TO ASSESS TRANSFORMATION CAPABILITY OF THE SYSTEM (Experiment No. 1)

V-3.1 DESCRIPTION OF THE TEST FIELD

An office chair was placed in a convenient position, standing in such a way that all the four legs and corners were visible from both the camera stations. An arbitrary coordinate system was assumed and with reference to this system the object space coordinates of all the points were measured to 1/10 of a millimeter (Plates V-1 and V-2).

V-3.2 CHECK POINT DISCREPANCIES

After transforming the comparator/digitizer coordinates into the photo-coordinates by using conformal transformation and then the photo-coordinates into the object space coordinates by Bundle Adjustment, as detailed in the paragraphs V-2.3 and V-2.4, the next step was to compare these photogrammetrically computed object space coordinates with the actual measured ground coordinates, to check the discrepancies.

Thus to assess the accuracy of the system the RMS errors at six check points were determined. Table V-1 gives a summary of the results thus obtained.

Point	X(cm)	Y(cm)	Z(cm)
1	13.21	0.31	61.74
2	16.81	0.29	64.15
4	36.63	0.20	21.17
6	39.31	0.31	23.38
7	45.53	0.09	83.83
8	57.54	0.05	86.16
9	73.74	0.30	41.26
10	76.72	0.63	42.74
13	76.75	66.60	46.46
14	39.99	67.34	84.08
16	12.85	67.38	57.87
18	36.12	67.31	22.77

TABLE V-1(a) : LIST OF CONTROL POINT OBJECT SPACE COORDINATES (Experiment No.1)

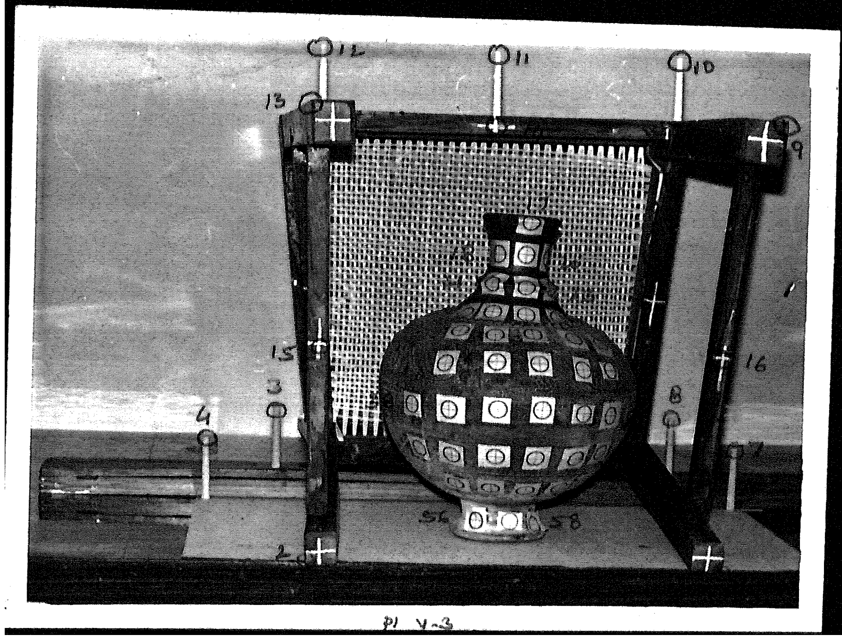
DIGITIZER			AUTOGRAPH A-8			COMPARATOR		
v_X (mm)	v_Y (mm)	v_Z (mm)	v_X (mm)	v_Y (mm)	v_Z (mm)	v_X (mm)	v_Y (mm)	v_Z (mm)
+11.40	+10.10	+17.36	+11.67	+11.15	+19.91	+11.49	+11.60	+19.16
-39.60	-15.76	+14.48	-39.26	- 5.96	-10.03	-41.76	- 2.45	+12.82
+12.62	-13.49	-21.34	+11.67	-17.54	-43.64	+12.82	- 2.12	-21.75
+13.00	- 7.47	- 8.98	-13.09	- 7.33	- 8.08	-11.91	- 9.30	- 8.26
+27.65	+22.65	+14.95	+27.73	23.51	+14.73	+29.27	+23.15	+17.26
+ 9.69	- 3.09	- 9.75	- 9.64	-3.82	-12.70	-11.51	- 3.36	-10.40
24.02	13.64	16.53	23.86	12.48	23.85	25.16	13.50	17.17
128.9	73.20	8.264	128.00	67.00	11.93	135.00	72.40	8.59

1 : CHECK POINT DISCREPANCIES (Experiment No. 1)

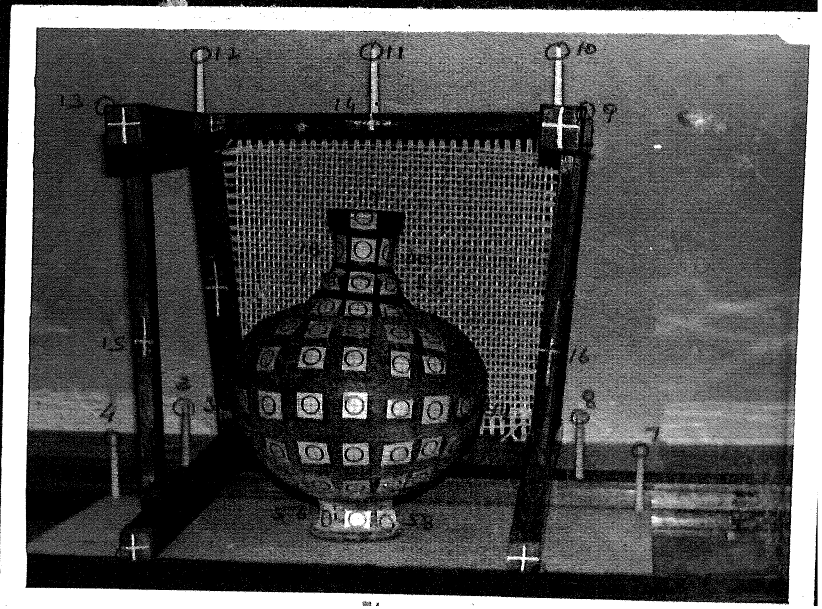
RMS Error $= \sqrt{\frac{\sum_{i=1}^{N} v_i^2}{N-1}}$ N = Number of observations, v_i = Residuals.

Enlargement ratio = 4.66

Average photo scale= 1.40



Pl V-3



Point	X(cm)	Y(cm)	Z(cm)
2	19.33	0.00	88.46
3	17.82	12.32	48.68
4	8.62	8.54	51.89
5	65.23	0.00	88.45
7	76.30	8.15	52.10
8	69.21	11.80	47.98
9	69.80	50.43	88.45
10	68.51	58.72	57.19
11	43.65	58.56	55.19
12	21.76	58.63	57.35
13	18.25	50.14	90.08

TABLE V-2(a) : LIST OF CONTROL POINT OBJECT SPACE COORDINATES (Experiment No.2)

V-4 EXPERIMENT TO ASSESS CONTOURING CAPABILITY OF TRANSFORMED COORDINATES (Experiment No.2)

V-4.1 DESCRIPTION OF THE TEST FIELD

An office chair was made to lie on its back with the four legs facing the camera. In between these four legs a properly targetted mud pot was placed. As in the previous experiment an arbitrary coordinate system was assumed and with reference to this system, the object space coordinates of all the points were measured to 1/10 of a millimeter (Plates V-3 and V-4).

V-4.2 CHECK POINT DISCREPANCIES

The photogrammetrically computed object space coordinates were then compared with the actual ground coordinates of the points to assess the accuracy of the system, as in the previous case. RMS errors at 3 check points were determined. Table V-2 gives a summary of the results thus obtained.

Point	v_X (mm)	v_Y (mm)	v_Z (mm)
14	-0.057	-0.058	3.89
15	-2.268	-1.92	3.298
16	-0.00095	0.117	3.24
RMS Errors	1.604	1.361	4.272
RMS Errors on Negative Scale/ Depth‰	8.605	7.302	2.136

TABLE V-2 : CHECK POINT DISCREPANCIES (Experiment No.2)

GRAPHICS AND CONTOURING FROM THE TRANSFORMED COORDINATES

VI-1 INTRODUCTION

In the previous chapter the accuracy of the system consisting of the Non-metric camera and the Digitizer was analysed through the discrepancies at the well distributed check points over the entire depth of field of the photography. But the ultimate goal of any photogrammetry is to make maps out of the photographs and the measurements made on them. Thus the experiment No.1 with the chair alone was selected to check the graphic capability of the system and the experiment No.2 with the mud pot to check the contouring capability.

VI-2 GRAPHIC CAPABILITY

The object space coordinates computed photogrammetrically were plotted manually for all the three cases viz. measurements on the enlarged photograph with the digitizer and the Autograph A-8 and measurements on the 35 mm film negative with the comparator(Fig. VI-2). Table VI-1 gives the X, Y, Z coordinates of the points plotted in all the three cases.

Point	DIGITIZER			AUTOGRAPH A-8			COMPARATOR		
	X (cm)	Y (cm)	Z (cm)	X (cm)	Y (cm)	Z (cm)	X (cm)	Y (cm)	Z (cm)
1	12.66	0.16	61.75	12.67	0.18	61.75	13.18	0.30	61.74
4	37.09	0.29	21.21	37.05	0.28	21.20	36.66	0.21	21.18
8	56.05	0.10	85.76	56.05	0.09	85.75	57.45	0.05	86.14
10	76.96	0.88	42.78	76.96	0.89	42.78	76.74	0.65	42.74
11	71.79	48.17	48.76	71.88	48.21	47.99	71.77	48.24	48.81
13	75.90	66.52	46.19	75.91	66.54	46.19	76.70	66.70	46.44
14	42.44	67.62	84.60	42.44	67.63	84.60	40.44	67.36	84.11
21	56.31	48.95	86.14	56.25	48.50	85.75	57.14	49.25	86.15
22	13.45	49.79	63.42	13.34	49.34	62.35	13.45	49.35	62.55
16	11.62	67.13	57.82	11.61	67.10	57.82	12.78	67.37	57.86
18	36.31	66.76	22.72	36.32	66.75	22.72	36.13	67.28	22.77
23	37.15	48.35	24.80	37.14	48.35	24.75	38.42	48.56	24.85
25	12.29	34.36	62.75	12.18	34.16	62.16	12.19	35.34	61.82
24	56.90	35.15	86.39	56.25	35.06	36.15	56.35	36.15	86.20

TABLE VI-1 : COMPUTED OBJECT SPACE COORDINATES (FOR ASSESSING GRAPHIC CAPABILITY)

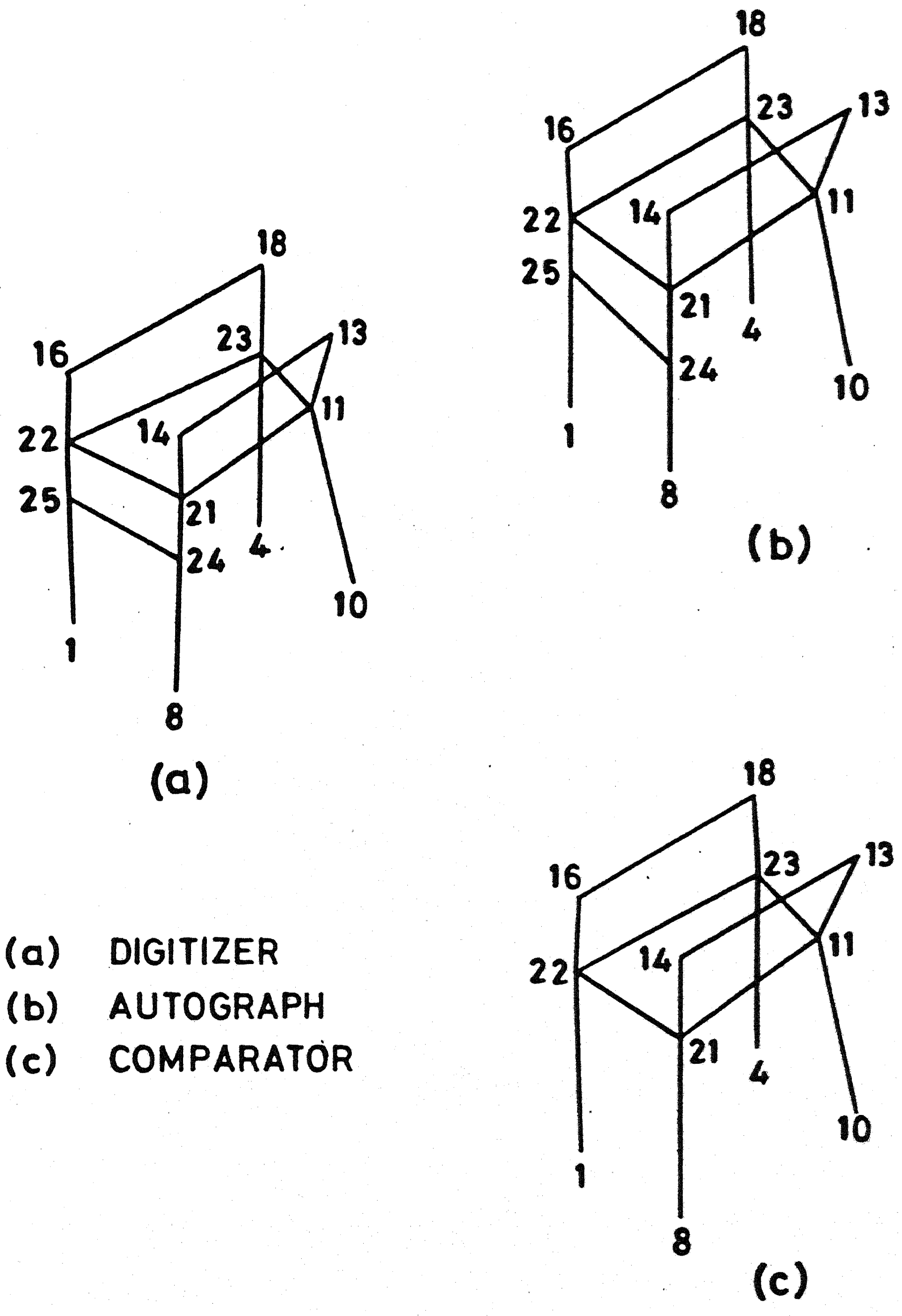


FIG. VI-9 GRAPHIC CAPABILITY OF THE SYSTEM.

VI-3 CONTOURING CAPABILITY

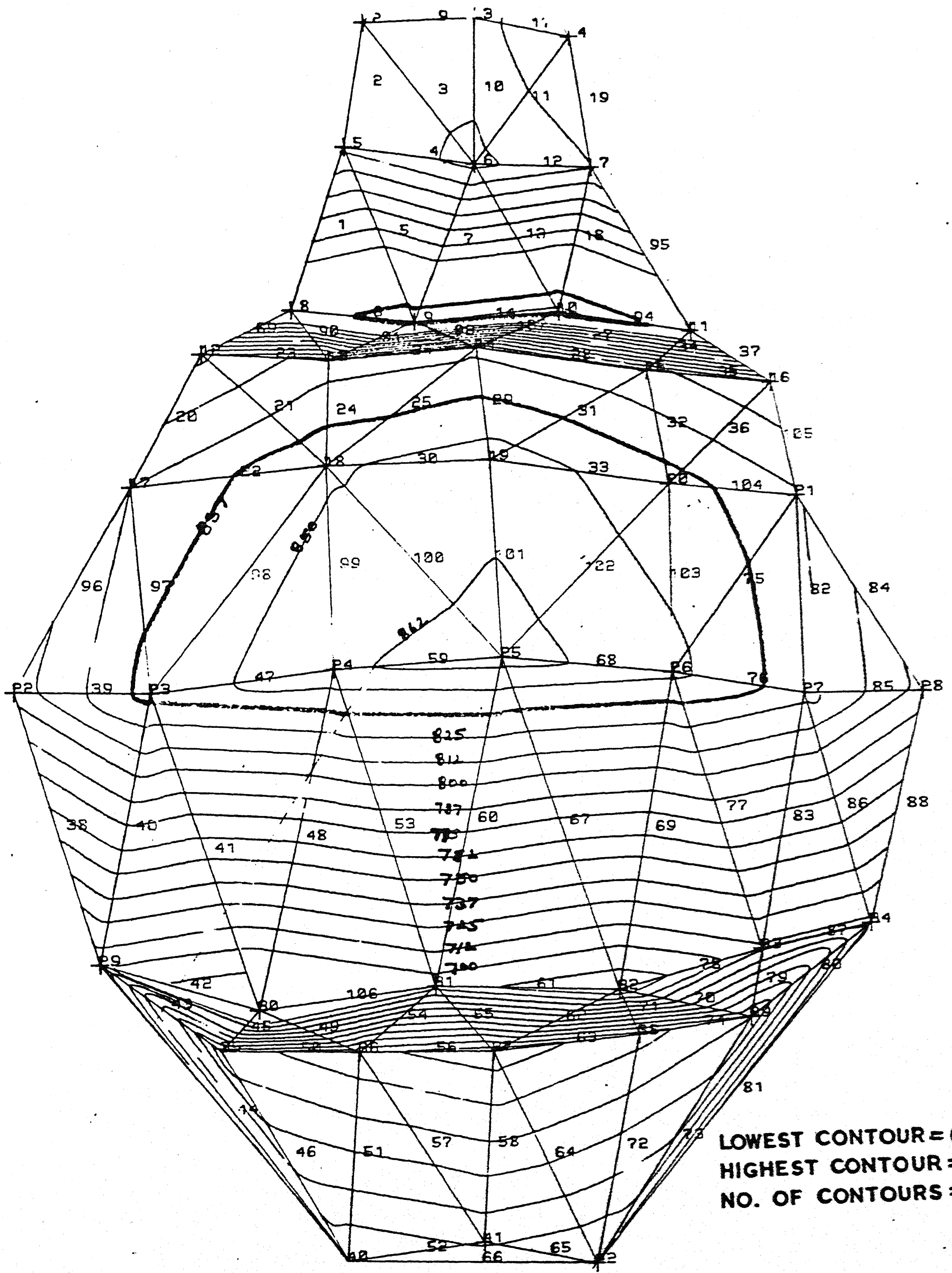
The photogrammetrically computed X, Y, Z object space coordinates of the target points placed on the mud pot were fed into the contouring program available at CAD-P Centre, IIT-Kanpur.

VI-3.1 CONTOURING PROGRAM

This contouring program consists of two programs:

1) Triangulation program - VORN
2) Contouring program - MOH3

This is a program which draws contours for a set of random X, Y, Z coordinates. Input to the program is a listing of the X, Y, Z coordinates, number of contours required and contour interval. The program VORN first does the triangulation and then the program MOH3 interpolates and draws the contours. Sixteen colours may be used in drawing the contours on the console. However when the contours are plotted on the Hewlett Packard Plotter only four colours can be used. Even then the first three colours are used for the first three contours and for rest of the contours only the last colour is used. There is no provision for writing the values of the contours in the map itself. However an index may be given for different colour coded contours.



LOWEST CONTOUR = 650mm
HIGHEST CONTOUR = 862mm
NO. OF CONTOURS = 23

FIG. VI-3 CONTOUR MAP OF POT.

To get a hard copy, contours can be plotted on the Hewlett Packard Plotter attached to the micro-computer. Fig. VI-3 shows the contour map of the pot.

ANALYSIS OF RESULTS

VII-1 INTRODUCTION

The work has been carried out in three phases namely the calibration of the camera-enlarger system, assessment of the check point discrepancies and the assessment of the system for graphic and contouring capabilities. Hence the results obtained from various experiments will be analysed under the same headings.

VII-2 CALIBRATION OF THE CAMERA ENLARGER SYSTEM

With measurements on 35 mm film negative with the comparator a value of 51.037 mm for the calibrated Focal length has been obtained, as against the nominal Focal length of 50 mm. This 50 mm focal length is when focussed at infinity. This value of 51.037 mm is quite possible and understandable as in the non-metric cameras though enough care is taken to properly fix the total length, it cannot be compared to the accuracies of a metric camera and the above discrepancy is but natural. Also the experiments that have been conducted are not for infinite object distances but for close range applications, the camera-object distance being as small as 2.0 m. Hence the calibrated Focal length of 51.037 mm is quite in order.

But on enlargement and after projection printing on the bromide paper the value of calibrated focal length has deviated, contrary to the normal assumption that the inner orientation parameters in the case of an enlarged photograph can be obtained just by multiplying the values obtained in the case of 35 mm film negative (Welch et al., 1983). The reason for this may be, on the one hand the large shrinkages involved in the case of paper prints and on the other hand may be due to the influence of the enlarger lens distortion characteristics. However this poses some problems, as, for each and every enlargment ratio the system is to be calibrated, since the distortion characteristics of the enlarger lens may vary with the setting and focussing of the enlarger lens. This is one of the draw-backs of the system.

The results obtained from the measurements on the enlarged photographs using the digitizer (500 microns least count) and the plotting table of wild A-8 Autograph (10 microns least count) are similar. This is due to the reason that the distance between the image points, the coordinates of which have been measured is much more than 500 microns, the least count of the digitizer. With proper pointing both the set-ups should give the same results. But if the distance between the points is less than or even equal to 1 millimeter the results obtained from the Digitizer measurements may be erroneous. However

for close range photogrammetric work is should not matter much.

The Radial distortion curves obtained in the case of 35 mm film negative and the enlarged photographs are also different (Fig. IV-4 and IV-5). This is due to the influence of the enlarger lens distortion characteristics. However both the curves show a peak which indicates that the distortion at a particular part of the film is sharply changing compared to the rest, the inference which may be drawn from here. Distortion in the case of enlarged prints is maximum at the centre attaining a peak value of 0.33 mm whereas in the case of direct measurement on 35 mm film a situation of zero distortion occurs at 15.5 mm . In the second case however there is a small kink at 7.5 mm which may be attributed to a minor measurement error or a local distortion at that point due to inaccuracies of transport mechanism and holding of film in the frame.

Even though an overall mean distribution of errors have been considered in computing the calibration focal length and other inner orientation parameters, it was found during the study that for each diagonal the distortion characteristics varied. This is due to the reason that the lenses of nonmetric cameras are not made for photogrammetric work and this type of random variation in the

distortion characteristics are possible. More so, while in the process of enlargment, the negative is sandwitched between two ordinary glass plates of the enlarger through which the light passes, the distortion patterns are pronounced and asymmetrical in nature. Since enough care was taken to ensure that the negative plane and the paper print easel were parallel during exposure, such errors however could not be due to non-parallelism of the two planes. Shift of Principal Point away from the centre of photograph may be the cause of nonhomogeneity and anisotropy of the lens or the lack of proper centering of the lens. In the simple cameras, not much care is given to these aspects and hence large values of principal point offset could be expected. The results in Tables IV-3.1, IV-3.2 and IV-3.3 show that the values of Principal Point Offset are negligibly small. This is an indication that by chance the camera utilised for the purpose did not have considerable errors in lens assembly.

Measurements made at different locations along the length of the film have revealed that there is not much change between the parameters. However some variations were expected from exposure to exposure. The negligibly small difference may be due to two reasons.

(a) The lid of the camera pushes forward the stretched film resulting in a possible flattening, thus avoiding considerable variation in deformation of the exposed frames.

(b) The measuring instruments may not be sufficiently accurate to bring out the minor changes due to the film deformation which may be in the order of 20-30 microns or more. Particularly with the digitizer of low resolution used for the purpose it could not have been possible to determine.

However from the results shown in Tables IV-3.1, IV-3.2, and IV-3.3 it is inferred that variations of coordinates is non-existent. This is attributed to the very accurate pointing upon the images of the target for calibration purposes.

VII-3 ASSESSMENT OF CHECK POINT DISCREPANCIES

Experiments conducted to assess the check point discrepancies and hence the transformation capabilities of the entire system show that in the first case the RMS errors (Table V-1) are comparatively higher than of the second case. In the first case the three dimensional object (Chair) selected did not have sharp corners. This resulted in erroneous pointings. But in the second case because of the sharp corners, pointings could be made very accurately and hence there is an appreciable refinement in the RMS values upon check points.

But even then the accuracy in the direction of depth (2.136/1000) seems to be higher. This is because of the

reason that only a very few parameters have been considered for image refinement. If more number of parameters and higher order terms are used for image refinement, the accuracy is expected to further improve.

Also only two pointings have been made on each image point. This will only check the previous pointing. But if a number of pointings had been made and a statistical average had been taken, it is felt that the results would have improved.

VII-4 GRAPHICS AND CONTOURING CAPABILITIES OF THE SYSTEM

Since the ultimate goal of the exercise is mapping, the Graphics and contouring capabilities of the system have been tested. Figure VI-? indicates that the system could be utilised for discrete point mapping even though continuous plotting is not possible. The small variations in shape may be due to the pointing inaccuracies upon the rounded corners of the object.

In the second experiment, where the control points were sharp and had been very accurately measured to first place of decimal nearly accurate transformation of target points was achieved. In the top and bottom portion, however the drawing did not come out too well because of placement of targets which when done with better care may provide very clear picture in this portion too. With slight modification

of the program it will also be possible to put the contour values which have been manually written at present.

It is thus seen that where the shape of an object is to be drawn through contours, this method will suitably be able to be employed.

CONCLUSIONS, SUGGESTIONS AND RECOMMENDATIONS

VIII-1 CONCLUSIONS

From the various investigations in this thesis, the following conclusions can be drawn:

1. Since in the case of enlarged photographs, the enlarger lens also plays a part, the calibrated focal length is not in direct relationship with that obtained using the comparator where the negative was directly measured. However the comparaable results of the calibrated focal length and other inner orientation parameters obtained from Wild A-8 and the digitizer show that the digitizer can be used as a substitute to the coordinate measuring device in photogrammetry.

2. It is not very necessary to provide the Fiducial marks to the amateaur camera. The inner orientation parameters can otherwise also be calculated by following the methods as in the present work.

3. Though generally photogrammetric measurements on paper prints are not recommended yet in this case where the entire system has been calibrated taking into account the target field image on paper print, it is found that the achieved accuracy is comparable

to measurements on polyster based positive prints.

4. The digitizer used was of low resolution. But it has been seen that when careful and accurate pointing has been done with a cross-shaped cursor of the digitizer, the check point accuracy in plan is extremely well proved. Comparatively in depth, the inaccuracy is slightly higher. As in the normal photogrammetric work, this accuracy can be improved by increasing the number of control points indepth and evaluating higher order parameters for required transformation.

Overall it can be said that if accurate and careful pointing is done, lower resolution of digitizer to this extent, may not be a constraint in accurate evaluations of coordinates.

5. Using the three differently obtained focal lengths, photo-coordinates of measured points in the three separate cases were transformed to space coordinate system.

The check point accuracies obtained in all the three cases were comparable and further proved that digitizer - nonmetric camera system could play a major role in very much reducing the presently exhorbitant costs of photogrammetric control provision and mapping through discrete points.

6. The points measured on photographs must be sharp and control points accurately measured, otherwise as is clear from Table V-1 and the standard errors shown in Appendix B, the results may not be accurate.

7. An application of this method in drawing shapes of objects through contours, has however established that this method can prove to be extremely inexpensive Remote Sensing Technique in manufacturing industries.

VIII-2 SUGGESTIONS AND RECOMMENDATIONS

1. At present the work has been conducted with camera mounted on a tripod, kept normal to object and nearly levelled. Further experiments may be held with general case in terrestrial photogrammetry and with hand-held cameras.

2. Further investigations may continue on a suitably linked Super Micro Digitizer - micro computers system along with the entire calibration, transformation, mapping package and plotter to improve the efficiency of the system.

3. To make the method versatile, the camera should be calibrated at different distances and calibration curve plotted from which suitability of combinations for different camera-object distances and different types of photography may be verified.

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APPENDIX A

DETAILS OF INSTRUMENTS USED

APPENDIX A

DETAILS OF THE INSTRUMENTS USED

CAMERA - 35 mm single-lens Reflux (SLR) Canon
Focal plane shutter.
Format: 24 mm x 36 mm.
Lens : FD 50 mm f 1.4

FILM - INDU Panchromatic miniature roll film
125 ASA/22 DIN.

BROMIDE PAPER - INDU Special, double weight.

ENLARGER - Belvish Photographic Enlarger (Professional).

DIGITIZER - Tectronix Tablet Digitizer.
Effective Digitizing area 297.2 mm x 297.2 mm.

Pug: 4 button cursor.
Pixel size : 500 microns , Cursor size : 250 microns.

PLOTTER: Hewlett Packard Plotter.

APPENDIX B

LISTING OF COMPUTER PROGRAMS AND INPUT OUTPUT DATA

```
0000000001111111111222222222233333333334444444444555555555566666666667777777777
2345678901234567890123456789012345678901234567890123456789012345678901234567678

C ----------------------------------------------------------------------------
C THIS PROGRAM FINDS THE MINIMAL LEAST SQUARE SOLUTION OF EQUATIONS
C PROVIDED THE NUMBER OF EQUATIONS ARE MORE THAN THE UNKNOWNS.
C M       =NUMBER OF EQUATIONS.
C N       =NUMBER OF UNKNOWNS.
C NAG SUBROUTINE F04JAF IS USED.
C TO EXECUTE-----EX L.FOR,/SEA PUB:NAG.REL
C ----------------------------------------------------------------------------
            REAL SIGMA,TOL,A(10,6),B(10),WORK(16)
            INTEGER I,IFAIL,IRANK,J,LWORK,M,N,NRA
            NRA=10
            LWORK=16
            IFAIL=0
            M=5
            N=1
            TOL=5.0E-4
            DO 20 I=1,N
            READ(21,*) (A(J,I),J=1,M)
   20       CONTINUE
            READ(21,*) (B(I),I=1,M)
            WRITE(22,99996)
            WRITE(22,99992) ((A(I,J),J=1,N),I=1,M)
            WRITE(22,99995)
            WRITE(22,99992) (B(I),I=1,M)
            CALL F04JAF(M,N,A,NRA,B,TOL,SIGMA,IRANK,WORK,LWORK,IFAIL)
            WRITE(22,99994)
            WRITE(22,*) (B(I),I=1,N)
            WRITE(22,99993)SIGMA,IRANK
            STOP
 99996      FORMAT(9H MATRIX A)
 99995      FORMAT(9H VECTOR B)
 99994      FORMAT(16H SOLUTION VECTOR)
 99993      FORMAT(1X,'STANDARD ERROR=',F6.3,5X,'RANK=',I2)
 99992      FORMAT(1X,5F12.3)
            END
C ----------------------------------------------------------------------------
```

```
0  000000011111111112222222222333333333344444444445555555555666666666677777777778888888888
345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

      C ---------------------------------------------------------------------
      C THIS PROGRAM TRANSFORMS THE COORDINATES IN THE COMPARATOR OR
      C DIGITISER COORDINATE SYSTEM IN TO THE PHOTO FIDUCIAL
      C COORDINATE SYSTEM.IT ALSO APPLIES CORRECTIONS FOR THE RADIAL
      C LENS DISTORTION AND PRINCIPAL POINT SHIFT.
      C ---------------------------------------------------------------------
              READ LBCX,LBCY,LTCX,LTCY,LBED,LLED
      C ---------------------------------------------------------------------
      C LBCX  =X COORDINATE OF LEFT BOTTOM CORNER.
      C LBCY  =Y COORDINATE OF LEFT BOTTOM CORNER.
      C LTCX  =X COORDINATE OF LEFT TOP CORNER.
      C LTCY  =Y COORDINATE OF LEFT TOP CORNER.
      C LLED  =LENGTH OF LEFT EDGE.
      C LBED  =LENGTH OF BOTTOM EDGE.
      C ---------------------------------------------------------------------
              READ(21,*)N,RLDC,PPX,PPY
      C ---------------------------------------------------------------------
      C N     =NUMBER OF POINTS ON THE PHOTOGRAPH.
      C RLDC  =RADIAL LENS DISTORTION COEFICIENT.
      C PPX   =PRINCIPAL POINT SHIFT IN X DIRECTION.
      C PPY   =PRINCIPAL POINT SHIFT IN Y DIRECTION.
      C RBCX  =X COORDINATE OF RIGHT BOTTOM CORNER.
      C RBCY  =Y COORDINATE OF RIGHT BOTTOM CORNER.
      C ---------------------------------------------------------------------
              READ(21,*)LBCX,LBCY,RBCX,RBCY,LTCX,LTCY
              LBED=SQRT((LBCX-RBCX)**2+(LBCY-RBCY)**2)
              LLED=SQRT((LBCX-LTCX)**2+(LBCY-LTCY)**2)
      C ---------------------------------------------------------------------
      C CLBFMX,CLBFMY,CRBFMX,CRBFMY---ARE THE COORDINATES OF THE LEFT
      C AND RIGHT BOTTOM CORNERS IN THE FIDUCIAL AXES SYSTEM.
      C ---------------------------------------------------------------------
              CLBFMX=-LBED/2.0
              CLBFMY=-LLED/2.0
              CRBFMX=LBED/2.0
              CRBFMY=-LLED/2.0
              ALPHA=ATAN((RBCY-LBCY)/(RBCX-LBCX))
              XC1=LBCX*COS(ALPHA)
              YS1=LBCY*SIN(ALPHA)
              XS1=LBCX*SIN(ALPHA)
              YC1=LBCY*COS(ALPHA)
              XC=XC1-YS1
              YC=XS1+YC1
              TX=CLBFMX-XC
              TY=CLBFMY-YC
      C ---------------------------------------------------------------------
```

```
C ALPHA =ROTATION OR TILT OF THE PHOTOGRAPH.
C TX    =TRANSLATION IN X DIRECTION.
C TY    =TRANSLATION IN Y DIRECTION.
C ---------------------------------------------------------------------------
         ICOUNT=0
  10     READ(21,*)X,Y
         ICOUNT=ICOUNT+1
         XC2=X*COS(ALPHA)
         YS2=Y*SIN(ALPHA)
         XS2=X*SIN(ALPHA)
         YC2=Y*COS(ALPHA)
         XC3=XC2-YS2+TX
         YC3=XS2+YC2+TY
         RLX=RLDC*XC3*(XC3**2+YC3**2)
         RLY=RLDC*YC3*(XC3**2+YC3**2)
         XCOR=XC3+RLX-PPX
         YCOR=YC3+RLY-PPY
         IF(ICOUNT.GT.N)GO TO 20
         WRITE(22,30)XCOR,YCOR
         GO TO 10
  20     STOP
  30     FORMAT(1X,F12.3,',',F12.3)
         END
C ---------------------------------------------------------------------------
```

EXPERIMENT 1

Plates V-1, V-2

DIGITIZER

INPUT DATA

Photo Coordinates

```
4,1,-3.398,-45.296,0.01
4,2,1.431,-46.375,0.01
4,3,4.193,-44.815,0.01
4,4,20.921,-37.012,0.01
4,5,23.125,-37.356,0.01
4,6,25.172,-36.639,0.01
4,7,51.449,-52.782,0.01
4,8,58.054,-53.462,0.01
4,9,63.258,-41.580,0.01
4,10,67.569,-41.905,0.01
4,11,67.895,8.542,0.01
4,12,54.523,10.365,0.01
4,13,68.862,27.995,0.01
4,14,61.856,40.632,0.01
4,15,2.214,-1.654,0.01
4,16,-0.956,38.324,0.01
4,18,21.581,27.362,0.01
4,20,22.854,-27.752,0.01
5,1,-64.621,-40.120,0.01
5,2,-61.508,-41.478,0.01
5,3,-56.702,-40.325,0.01
5,4,-29.475,-33.125,0.01
5,5,-26.574,-33.184,0.01
5,6,-24.632,-32.959,0.01
5,7,-18.589,-47.584,0.01
5,8,-12.953,-48.723,0.01
5,9,8.421,-37.165,0.01
5,10,12.184,-37.458,0.01
5,11,9.852,13.651,0.01
5,12,-18.263,15.735,0.01
5,13,10.850,33.623,0.01
5,14,-12.158,45.865,0.01
5,15,-61.295,1.752,0.01
5,16,-63.639,40.685,0.01
5,18,-27.984,30.685,0.01
5,20,-28.041,-23.765,0.01
```

COLUMN 1 = PHOTO NUMBER
COLUMN 2 = POINT NUMBER
COLUMN 3 = X- COORDINATE (MM)
COLUMN 4 = Y- COORDINATE (MM)
COLUMN 5 = TEMP (WEIGHTAGE).

DATA FILE NAME = ZD1.DAT

Survey Data

```
1,1,1,1,13.21,0.31,61.74,0.01,0.01,0.01
2,2,2,2,16.81,0.29,64.15,0.01,0.01,0.01
3,3,3,3,18.32,0.31,59.26,0.00,0.00,0.00
4,4,4,4,36.63,0.20,21.17,0.01,0.01,0.01
5,5,5,5,38.16,0.20,21.17,0.00,0.00,0.00
6,6,6,6,39.31,0.31,23.38,0.01,0.01,0.01
7,7,7,7,45.53,0.09,83.83,0.01,0.01,0.01
8,8,8,8,57.54,0.05,86.16,0.01,0.01,0.01
9,9,9,9,73.74,0.30,41.26,0.01,0.01,0.01
```

COLUMN 1,3 = NAME, COLUMN 4 = POINT
COLUMN 5 = X COORDINATE (CMS)
COLUMN 6 = Y COORDINATE (CMS)
COLUMN 7 = Z COORDINATE (CMS)
COLUMNS 8-10 = WEIGHTAGES

DATA FILE NAME = ZD1.DAT

RESULTS

RESULTS
EXTERIOR ORIENTATION
RESULT FILE NAE: FOR11.DAT

PHOTO NO. 4	XO(CMS)	YO(CMS)	ZO(CMS)	KAPPA(RAD.)	PHI(RAD.)	OMEGA(RAD.)
	-14.426	36.386	242.991	0.835322D-01	-0.134602D+00	-0.493346D-02
STD. ERROR	0.5769D+01	0.6157D+01	0.4061D+01	0.2115D-01	0.2996D-01	0.3102D-01
RESIDUALS	0.2763D+02	-0.6386D+01	0.7009D+01	-0.8253D-01	0.1356D+00	0.5033D-02
WEIGHTS	0.000	0.000	0.000	0.000	0.000	0.000

VARIANCE /COVARIANCE MATRIX

0.33279E+02	0.75818E+00	0.54547E+01	0.88175E-03	0.16815E+00	-0.50860E-02
0.75818E+00	0.37909E+02	-0.20545E+01	-0.52099E-01	0.89185E-03	-0.18864E+00
0.54547E+01	-0.20545E+01	0.16493E+02	0.53242E-02	0.50454E-01	0.14857E-01
0.88175E-03	-0.52099E-01	0.53242E-02	0.44738E-03	0.35023E-04	0.20473E-03
0.16815E+00	0.89185E-03	0.50454E-01	0.35023E-04	0.89731E-03	-0.77089E-05
-0.50860E-02	-0.18864E+00	0.14857E-01	0.20473E-03	-0.77089E-05	0.96212E-03

PHOTO NO. 5	XO(CMS)	YO(CMS)	ZO(CMS)	KAPPA(RAD.)	PHI(RAD.)	OMEGA(RAD.)
	39.578	36.120	252.631	0.583987D-01	-0.117683D+00	-0.256960D-02
STD. ERROR	0.6129D+01	0.6395D+01	0.3963D+01	0.2040D-01	0.3084D-01	0.3186D-01
RESIDUALS	0.3147D+02	-0.6120D+01	-0.2631D+01	-0.5740D-01	0.1187D+00	0.2670D-02
WEIGHTS	0.000	0.000	0.000	0.000	0.000	0.000

VARIANCE /COVARIANCE MATRIX

0.37562E+02	-0.25666E+00	0.11514E+01	0.41081E-02	0.18758E+00	0.21466E-02
-0.25666E+00	0.40899E+02	-0.26129E+01	0.44618E-02	-0.11614E-02	-0.20181E+00
0.11514E+01	-0.26129E+01	0.15702E+02	-0.57929E-03	0.58647E-02	0.17866E-01
0.41081E-02	0.44618E-02	-0.57929E-03	0.41600E-03	0.45783E-04	0.22653E-04
0.18758E+00	-0.11614E-02	0.58647E-02	0.45783E-04	0.95122E-03	0.12990E-04
0.21466E-02	-0.20181E+00	0.17866E-01	0.22653E-04	0.12990E-04	0.10151E-02

OUTPUT FILE: FOR 22.DAT

X(cms)	Y(cms)	Z(cms)
12.6619,	0.1594,	61.7485
16.1571,	0.0598,	64.1782
17.1799,	-0.7034,	57.5235
37.0864,	0.2859,	21.2084
42.1241,	0.3576,	19.7219
40.0340,	0.5263,	23.4233
46.1330,	0.1844,	83.9278
56.0475,	0.0965,	85.7547
73.9024,	0.5821,	41.2645
76.9568,	0.8833,	42.7787
71.7877,	48.1649,	48.7637
45.3057,	46.2476,	85.6978
75.8999,	66.5201,	46.1880
42.3976,	67.6211,	84.5960
12.0448,	34.2354,	61.4554
11.6177,	67.1278,	57.8230
36.3058,	66.7633,	22.7188
40.0993,	10.3099,	23.8251

RESULTS

PHOTO COORDINATES

ALL WEIGHT S TAKEN AS 1000.0

OUTPUT FILE: FOR 23.DAT.

PHOTO NO.	POINT NO.	X(MM)	Y(MM)	VX(MM)	VY(MM)

PHOTO	POINT	x(mm)	y(mm)	Vx(mm)	Vy(mm)
4	1	-3.398	-45.296	-0.2823D+01	-0.8875D+00
4	2	1.431	-46.375	-0.2761D+01	-0.9506D+00
4	3	4.103	-44.815	-0.1100D-01	-0.1146D+00
4	4	20.921	-37.012	0.2404D+01	0.1483D+00
4	5	23.175	-37.356	-0.2109D-01	-0.2218D+00
4	6	25.172	-36.639	0.3210D+01	0.8594D+00
4	7	51.449	-52.787	0.2172D+01	0.6031D+00
4	8	58.054	-53.462	-0.5303D+01	0.1380D+01
4	9	63.258	-41.580	0.1055D+01	0.1533D+01
4	10	67.569	-41.905	0.1506D+01	0.1406D+01
4	11	67.895	8.542	-0.1564D-01	-0.1830D+00
4	12	54.523	10.365	-0.4427D-02	-0.5415D-01
4	13	68.962	27.995	-0.3805D+01	-0.5920D+00
4	14	61.956	40.632	0.9335D+01	0.1025D+00
4	15	2.214	-1.654	0.9871D-02	0.1089D+00
4	16	-0.956	38.321	-0.5410D+01	-0.4043D+00
4	18	24.581	27.362	0.7719D+00	-0.2926D+01
4	20	22.954	-27.757	-0.1394D-01	-0.1497D+00
5	1	-64.621	-40.120	-0.1621D+01	0.1084D-01
5	2	-61.508	-41.478	-0.2491D+01	-0.5066D+00
5	3	-56.702	-40.325	0.9888D-02	0.1164D+00
5	4	-29.475	-33.125	0.2187D+01	0.3776D+00
5	5	-26.574	-33.184	0.1641D-01	0.2246D+00
5	6	-24.632	-32.959	0.4061D+01	0.7677D+00
5	7	-18.589	-47.581	0.2317D+01	-0.2403D+00
5	8	-12.953	-48.723	-0.5727D+01	-0.2641D+00
5	9	8.421	-37.165	0.6298D+00	0.9570D+00
5	10	12.184	-37.458	0.8690D+00	0.7511D+00
5	11	9.352	13.651	0.1123D-01	0.1854D+00
5	12	-18.263	15.735	0.3495D-02	0.5507D-01
5	13	10.850	33.623	-0.4184D+01	0.4427D+00
5	14	-12.158	45.865	0.8451D+01	0.6439D+00
5	15	-61.295	1.752	-0.6974D-02	-0.1111D+00
5	16	-63.639	10.685	-0.4778D+01	-0.9384D+00
5	18	-27.994	30.685	0.5889D+00	-0.2563D+01
5	20	-28.041	-23.765	0.1074D-01	0.1516D+00

RESULTS

SURVEY COORDINATES

OUTPUT FILE:- FOR24.DAT

POINT NO. 1	X	Y	Z
	12.662	0.159	61.748
STD. ERROR	0.9936D+00	0.9967D+00	0.1130D+01

RESIDUALS	0.5481D+00	0.1506D+00	-0.8497D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.98724E+00	-0.56396E-02	0.55023E-03
-0.56396E-02	0.99339E+00	0.58368E-01
0.55023E-03	0.58368E-01	0.12769E+01

POINT NO. 2	X	Y	Z
	16.157	0.060	64.178
STD. ERROR	0.9916D+00	0.9942D+00	0.1130D+01
RESIDUALS	0.6529D+00	0.2302D+00	-0.2822D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.98334E+00	-0.60787E-02	-0.52530E-02
-0.60787E-02	0.98853E+00	0.60117E-01
-0.52530E-02	0.60117E-01	0.12759E+01

POINT NO. 3	X	Y	Z
	17.180	-0.703	57.524
STD. ERROR	0.2126D+01	0.3542D+01	0.1469D+02
RESIDUALS	0.1140D+01	0.1013D+01	0.1736D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.45192E+01	-0.11665E+01	-0.54628E+01
-0.11665E+01	0.12543E+02	0.41871E+02
-0.54628E+01	0.41871E+02	0.21583E+03

POINT NO. 4	X	Y	Z
	37.086	0.286	21.208
STD. ERROR	0.1040D+01	0.1039D+01	0.1134D+01
RESIDUALS	-0.4564D+00	-0.8595D-01	-0.3845D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10806E+01	-0.42317E-02	-0.22742E-01
-0.42317E-02	0.10789E+01	0.33963E-01
-0.22742E-01	0.33963E-01	0.12850E+01

POINT NO. 5	X	Y	Z
	42.124	0.358	19.722
STD. ERROR	0.3777D+01	0.4206D+01	0.2127D+02
RESIDUALS	-0.3964D+01	-0.1576D+00	0.1448D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.14266E+02	-0.93706E+01	-0.58776E+02
-0.93706E+01	0.17690E+02	0.71096E+02
-0.58776E+02	0.71096E+02	0.45227E+03

POINT NO. 6	X	Y	Z
	40.034	0.526	23.423
STD. ERROR	0.1038D+01	0.1037D+01	0.1133D+01
RESIDUALS	-0.7240D+00	-0.2163D+00	-0.4325D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10784E+01	-0.43843E-02	-0.26024E-01

-0.43843E-02	0.10760E+01	0.34449E-01
-0.26924E-01	0.34449E-01	0.12840E+01

POINT NO. 7	X	Y	Z
	46.133	0.184	83.928
STD. ERROR	0.9767D+00	0.9723D+00	0.1120D+01
RESIDUALS	-0.6030D+00	-0.9443D-01	-0.9784D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.95387E+00	-0.11182E-01	-0.67111E-01
-0.11182E-01	0.94540E+00	0.74100E-01
-0.67111E-01	0.74100E-01	0.12533E+01

POINT NO. 8	X	Y	Z
	56.048	0.096	85.755
STD. ERROR	0.9791D+00	0.9715D+00	0.1115D+01

1182E-01 0.94540E+00 0.74100E-01

-0.67111E-01	0.74100E-01	0.12533E+01

POINT NO. 8	X	Y	Z
	56.048	0.096	85.755
STD. ERROR	0.9791D+00	0.9715D+00	0.1115D+01
RESIDUALS	0.1492D+01	-0.4648D-01	0.4053D+00
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.95858E+00	-0.12565E-01	-0.86891E-01
-0.12565E-01	0.94374E+00	0.74413E-01
-0.86891E-01	0.74413E-01	0.12431E+01

POINT NO. 9	X	Y	Z
	73.902	0.582	41.254
STD. ERROR	0.1033D+01	0.1026D+01	0.1125D+01
RESIDUALS	-0.1624D+00	-0.2821D+00	-0.4463D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10667E+01	-0.64957E-02	-0.66816E-01
-0.64957E-02	0.10530E+01	0.39930E-01
-0.66816E-01	0.39930E-01	0.12647E+01

POINT NO. 10	X	Y	Z
	76.957	0.883	42.779
STD. ERROR	0.1032D+01	0.1025D+01	0.1123D+01
RESIDUALS	-0.2368D+00	-0.2533D+00	-0.3869D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10659E+01	-0.66678E-02	-0.70914E-01
-0.66678E-02	0.10509E+01	0.40071E-01
-0.70914E-01	0.40071E-01	0.12621E+01

POINT NO. 11	X	Y	Z
	71.788	48.165	48.764
STD. ERROR	0.5406D+01	0.2473D+01	0.1639D+02
RESIDUALS	0.1262D+01	-0.1349D+00	-0.2134D+01

0.29221E+02	0.48178E+01	-0.79879E+02
0.48178E+01	0.61168E+01	-0.16088E+02
-0.79879E+02	-0.16088E+02	0.26874E+03

POINT NO. 12	X	Y	Z
	45.306	46.248	85.698
STD. ERROR	0.2872D+01	0.1945D+01	0.1080D+02
RESIDUALS	-0.1306D+01	-0.7476D+00	-0.8978D+00
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.8245[illegible]E+01	0.14805E+01	-0.23601E+02
0.14805E+01	0.37844E+01	-0.71948E+01
-0.23601E+02	-0.71948E+01	0.11665E+03

POINT NO. 13	X	Y	Z
	75.900	66.520	46.188
STD. ERROR	0.1029D+01	0.1021D+01	0.1124D+01
RESIDUALS	0.8501D+00	0.7994D-01	0.2720D+00

WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10592E+01	0.57278E-02	-0.73297E-01
0.57278E-02	0.10429E+01	-0.36110E-01
-0.73297E-01	-0.36110E-01	0.12625E+01

POINT NO. 14	X	Y	Z
	42.398	67.621	84.596
STD. ERROR	0.9735D+00	0.9692D+00	0.1122D+01
RESIDUALS	-0.2408D+01	-0.2811D+00	-0.5160D+00
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.94771E+00	0.93935E-02	-0.61489E-01
0.93935E-02	0.93938E+00	-0.66177E-01
-0.61489E-01	-0.66177E-01	0.12590E+01

POINT NO. 15	X	Y	Z

	12.045	34.235	61.455
STD. ERROR	0.2035D+01	0.2054D+01	0.1405D+02
RESIDUALS	0.2765D+01	0.2265D+01	0.1495D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.41400E+01	-0.12440E-02	0.29368E+00
-0.12440E-02	0.42195E+01	0.21296E+01
0.29368E+00	0.21296E+01	0.19752E+03

POINT NO. 15	X	Y	Z
	11.618	67.128	57.823
STD. ERROR	0.9979D+00	0.1000D+01	0.1132D+01
RESIDUALS	0.1232D+01	0.2522D+00	0.4696D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.99571E+00	0.47246E-02	0.18535E-02
0.47246E-02	0.10006E+01	-0.47807E-01
0.18535E-02	-0.47807E-01	0.12811E+01

POINT NO. 18	X	Y	Z
	36.306	66.763	22.719
STD. ERROR	0.1038D+01	0.1037D+01	0.1134D+01
RESIDUALS	-0.1858D+00	0.5467D+00	0.5118D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10775E+01	0.36387E-02	-0.22672E-01
0.36387E-02	0.10753E+01	-0.29509E-01
-0.22672E-01	-0.29509E-01	0.12863E+01

POINT NO. 20	X	Y	Z
	40.099	10.310	23.325
STD. ERROR	0.3572D+01	0.3448D+01	0.2050D+02
RESIDUALS	-0.9693D+00	-0.3099D+00	-0.9751D+00
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.12760E+02	-0.60873E+01	-0.51817E+02
-0.60873E+01	0.11888E+02	0.48597E+02
-0.51817E+02	0.48597E+02	0.41009E+03

AUTOGRAPH A-8

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4,1,-3.277,-45.142,0.01
4,2,1.427,-46.363,0.01
4,3,4.003,-44.947,0.01
4,4,20.421,-37.097,0.01
4,5,23.612,-37.354,0.01
4,6,25.072,-36.720,0.01
4,7,51.447,-52.745,0.01
4,8,58.035,-53.459,0.01
4,9,63.269,-41.710,0.01
4,10,67.476,-41.908,0.01
4,11,67.531,8.471,0.01
4,12,54.513,10.308,0.01
4,13,68.953,28.130,0.01
4,14,62.070,40.633,0.01
4,15,2.214,-1.871,0.01
4,16,-0.979,38.027,0.01
4,18,24.581,27.101,0.01
4,20,22.937,-27.76[illegible],0.01
5,1,-64.614,-40.165,0.01
5,2,-61.507,-41.482,0.01
5,3,-56.702,-40.318,0.01
5,4,-29.482,-33.120,0.01
5,5,-26.578,-33.191,0.01
5,6,-24.619,-32.972,0.01
5,7,-18.587,-47.561,0.01
5,8,-12.925,-48.720,0.01
5,9,8.413,-37.169,0.01
5,10,12.187,-37.457,0.01
5,11,9.842,13.647,0.01
5,12,-18.252,15.741,0.01
5,13,10.850,33.612,0.01
5,14,-12.167,45.869,0.01
5,15,-61.294,1.781,0.01
5,16,-63.634,40.693,0.01
5,18,-27.897,30.690,0.01
5,20,-28.035,-23.755,0.01
1,1,1,1,13.21,0.31,61.74,0.01,0.01,0.01
2,2,2,2,16.81,0.29,64.15,0.01,0.01,0.01
3,3,3,3,18.32,0.31,59.26,0.00,0.00,0.00
4,4,4,4,36.63,0.20,21.17,0.01,0.01,0.01
5,5,5,5,38.16,0.20,21.17,0.00,0.00,0.00
6,6,6,6,39.31,0.31,23.38,0.01,0.01,0.01
7,7,7,7,45.53,0.09,83.93,0.01,0.01,0.01
8,8,8,8,57.54,0.05,36.16,0.01,0.01,0.01
9,9,9,9,73.74,0.39,41.26,0.01,0.01,0.01
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1,1,1,10,76.72,0.63,42.74,0.01,0.01,0.01
2,2,2,11,73.05,48.03,46.63,0.00,0.00,0.00
3,3,3,12,44.0,45.5,84.8,0.00,0.00,0.00
4,4,4,13,76.75,66.60,46.46,0.01,0.01,0.01
5,5,5,14,39.99,67.34,84.08,0.01,0.01,0.01
6,6,6,15,14.81,36.5,62.95,0.00,0.00,0.00
7,7,7,16,12.85,67.38,57.87,0.01,0.01,0.01
8,8,8,18,36.12,67.31,22.77,0.01,0.01,0.01
9,9,9,20,39.13,10.0,22.85,0.00,0.00,0.00
4,13.20,30.0,250.0,0.001,0.001,0.0001
5,71.0,30.0,250.0,0.001,0.001,0.0001
INPUT FOR THE FORTRAN BLOCK


  -229.978     2    18
  1000.000
   18     4
     13.200
     30.000
    250.000
      0.001
      0.001
      0.000
     0.000      0.000      0.000      0.000      0.000      0.000
     0.000      0.000      0.000      0.000      0.000      0.000
     0.000      0.000      0.000      0.000      0.000      0.000
     0.000      0.000      0.000      0.000      0.000      0.000
     0.000      0.000      0.000      0.000      0.000      0.000
     0.000      0.000      0.000      0.000      0.000      0.000
    -3.277    -45.142
    1     1   ***************
     13.210
      0.310
     61.740
 10000.000      0.000      0.000
     0.000  10000.000      0.000
     0.000      0.000  10000.000
     1.427    -46.363
    2     2   ***************
     16.810
      0.290
     64.150
 10000.000      0.000      0.000
     0.000  10000.000      0.000
```

RESULTS

EXTERIOR ORIENTATION

PHOTO NO. 4	XO(CMS)	YO(CMS)	ZO(CMS)	KAPPA(RAD.)	PHI(RAD.)	OMEGA(RAD.)
	-14.841	36.183	243.013	0.840297D-01	-0.136710D+00	-0.369446D-02
STD. ERROR	0.5796D+01	0.6196D+01	0.4074D+01	0.2118D-01	0.3011D-01	0.3121D-01
RESIDUALS	0.2804D+02	-0.6183D+01	0.6987D+01	-0.8303D-01	0.1377D+00	0.3794D-02
WEIGHTS	0.000	0.000	0.000	0.000	0.000	0.000

VARIANCE /COVARIANCE MATRIX

0.33598E+02	0.75086E+00	0.56294E+01	0.46737E-03	0.16981E+00	-0.50184E-02
0.75086E+00	0.38389E+02	-0.19953E+01	-0.52786E-01	0.87984E-03	-0.19105E+00
0.56294E+01	-0.19953E+01	0.16598E+02	0.51091E-02	0.51565E-01	0.14516E-01
0.46737E-03	-0.52786E-01	0.51091E-02	0.44854E-03	0.32902E-04	0.20813E-03
0.16981E+00	0.87984E-03	0.51565E-01	0.32902E-04	0.90645E-03	-0.75366E-05
-0.50184E-02	-0.19105E+00	0.14516E-01	0.20813E-03	-0.75366E-05	0.97411E-03

PHOTO NO. 5	XO(CMS)	YO(CMS)	ZO(CMS)	KAPPA(RAD.)	PHI(RAD.)	OMEGA(RAD.)
	39.564	36.001	252.628	0.587398D-01	-0.117441D+00	-0.198697D-02
STD. ERROR	0.6158D+01	0.6434D+01	0.3950D+01	0.2039D-01	0.3099D-01	0.3205D-01
RESIDUALS	0.3144D+02	-0.6001D+01	-0.2628D+01	-0.5774D-01	0.1184D+00	0.2087D-02
WEIGHTS	0.000	0.000	0.000	0.000	0.000	0.000

VARIANCE /COVARIANCE MATRIX

0.37924E+02	-0.28579E+00	0.11800E+01	0.36958E-02	0.18941E+00	0.22557E-02
-0.28579E+00	0.41392E+02	-0.25691E+01	0.46756E-02	-0.12955E-02	-0.20427E+00
0.11800E+01	-0.25691E+01	0.15682E+02	-0.59938E-03	0.59918E-02	0.17610E-01
0.36958E-02	0.46756E-02	-0.59938E-03	0.41554E-03	0.43712E-04	0.21514E-04
0.18941E+00	-0.12955E-02	0.59918E-02	0.43712E-04	0.96052E-03	0.13471E-04
0.22557E-02	-0.20427E+00	0.17610E-01	0.21514E-04	0.13471E-04	0.10273E-02

X(cm)	Y(cm)	Z(cm)
12.6727,	0.1756,	61.7460
16.1561,	0.0594,	64.1769
17.1531,	-0.8046,	57.2688
37.0520,	0.2625,	21.2009
42.0865,	0.7962,	22.1727
40.0340,	0.5246,	23.4240
46.1307,	0.1863,	83.9267
56.0492,	0.0927,	85.7532
73.9111,	0.5766,	41.2705
76.9575,	0.8884,	42.7788
71.8829,	48.2054,	47.9938
45.3090,	46.2330,	85.6083
75.9050,	66.5424,	46.1939
42.3992,	67.6260,	84.6024
12.0371,	34.1590,	61.4767
11.6138,	67.1036,	57.8177
36.3187,	66.7520,	22.7189
40.0939,	10.3825,	24.1282

RESULTS

PHOTO COORDINATES

ALL WEIGHT S TAKEN AS 1000.0

PHOTO NO. POINT NO. X(MM) Y(MM) VX(MM) VY(MM)

RESULTS

PHOTOCOORDINATES

ALL WEIGHTS TAKEN AS 1000.0

Ph. No	point	X (mm)	Y (mm)	Vx (mm)	Vy (mm)
4	1	-3.277	-45.142	-0.2725D+01	-0.7327D+00
4	2	1.427	-46.363	-0.2777D+01	-0.9205D+00
4	3	4.003	-44.947	-0.1545D-01	-0.1638D+00
4	4	20.421	-37.097	0.2036D+01	0.1274D+00
4	5	23.612	-37.354	-0.1523D-01	-0.1636D+00
4	6	25.072	-36.720	0.3205D+01	0.8426D+00
4	7	51.447	-52.745	0.2146D+01	0.6248D+00
4	8	58.035	-53.459	-0.5334D+01	0.1371D+01
4	9	53.269	-41.710	0.1164D+01	0.1457D+01
4	10	67.476	-41.908	0.1524D+01	0.1442D+01
4	11	67.531	8.471	-0.1582D-01	-0.1873D+00
4	12	54.513	10.308	-0.4212D-02	-0.5242D-01
4	13	68.953	28.130	-0.3710D+01	-0.3692D+00
4	14	62.070	40.633	0.9406D+01	0.1661D+00
4	15	2.214	-1.871	0.1694D-02	0.1765D-01
4	16	-0.979	38.027	-0.5448D+01	-0.5109D+00
4	18	24.581	27.101	0.8412D+00	-0.3976D+01
4	20	22.937	-27.763	-0.1176D-01	-0.1288D+00
5	1	-64.614	-40.105	-0.1625D+01	-0.2079D-01
5	2	-61.507	-41.482	-0.2494D+01	-0.5373D+00
5	3	-56.702	-40.318	0.1236D-01	0.1664D+00
5	4	-29.182	-33.120	0.2208D+01	0.3930D+00
5	5	-26.578	-33.191	0.1185D-01	0.1656D+00
5	6	-24.619	-32.972	0.4067D+01	0.7660D+00
5	7	-18.587	-47.561	0.2329D+01	-0.2479D+00
5	8	-12.975	-48.720	-0.5695D+01	-0.2799D+00
5	9	8.413	-37.169	0.6014D+00	0.9742D+00
5	10	12.187	-37.457	0.8631D+00	0.7608D+00
5	11	9.842	13.647	0.1125D-01	0.1895D+00
5	12	-18.252	15.741	0.3376D-02	0.5324D-01
5	13	10.850	33.612	-0.4216D+01	0.4154D+00
5	14	-12.167	45.869	0.8417D+01	0.6084D+00
5	15	-61.294	1.781	-0.9826D-03	-0.1805D-01
5	16	-63.634	40.693	-0.4799D+01	-0.9214D+00
5	18	-27.897	30.690	0.6334D+00	-0.2536D+01
5	20	-28.035	-23.755	0.9041D-02	0.1304D+00

RESULTS

SURVEY COORDINATES

POINT NO. 1	X	Y	Z
	12.673	0.176	61.746
STD. ERROR	0.9932D+00	0.9961D+00	0.1129D+01

RESIDUALS	0.5373D+00	0.1344D+00	-0.6010D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.98637E+00	-0.56780E-02	0.24981E-03
-0.56780E-02	0.99231E+00	0.58911E-01
0.24981E-03	0.58911E-01	0.12756E+01

POINT NO. 2	X	Y	Z
	16.156	0.059	64.177
STD. ERROR	0.9912D+00	0.9937D+00	0.1129D+01
RESIDUALS	0.6539D+00	0.2306D+00	-0.2686D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.98248E+00	-0.61139E-02	-0.55272E-02
-0.61139E-02	0.98746E+00	0.59775E-01
-0.55272E-02	0.59775E-01	0.12745E+01

POINT NO. 3	X	Y	Z
	17.153	-0.805	57.269
STD. ERROR	0.2129D+01	0.3522D+01	0.1460D+02
RESIDUALS	0.1167D+01	0.1115D+01	0.1991D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.45347E+01	-0.11813E+01	-0.55523E+01
-0.11813E+01	0.12403E+02	0.41247E+02
-0.55523E+01	0.41247E+02	0.21329E+03

POINT NO. 4	X	Y	Z
	37.052	0.282	21.201
STD. ERROR	0.1039D+01	0.1038D+01	0.1133D+01
RESIDUALS	-0.4220D+00	-0.8248D-01	-0.3093D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10796E+01	-0.42337E-02	-0.22828E-01
-0.42337E-02	0.10772E+01	0.33768E-01
-0.22828E-01	0.33768E-01	0.12837E+01

POINT NO. 5	X	Y	Z
	42.086	0.796	22.173
STD. ERROR	0.3729D+01	0.4095D+01	0.2064D+02
RESIDUALS	-0.3926D+01	-0.5962D+00	-0.1003D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.13904E+02	-0.89102E+01	-0.56214E+02
-0.89102E+01	0.16771E+02	0.56576E+02
-0.56214E+02	0.56576E+02	0.42615E+03

POINT NO. 6	X	Y	Z
	40.034	0.525	23.424
STD. ERROR	0.1038D+01	0.1037D+01	0.1133D+01
RESIDUALS	-0.7240D+00	-0.2146D+00	-0.4404D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10775E+01	-0.43841E-02	-0.26137E-01

-0.43841E-02	0.10749E+01	0.34249E-01
-0.26137E-01	0.34249E-01	0.12827E+01

POINT NO. 7	X	Y	Z
	46.131	0.196	83.927
STD. ERROR	0.9764D+00	0.9718D+00	0.1119D+01
RESIDUALS	-0.6007D+00	-0.9625D-01	-0.9671D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.95326E+00	-0.11151E-01	-0.67256E-01
-0.11151E-01	0.94444E+00	0.73647E-01
-0.67256E-01	0.73647E-01	0.12519E+01

POINT NO. 8	X	Y	Z
	56.049	0.093	85.753
STD. ERROR	0.9788D+00	0.9710D+00	0.1114D+01
RESIDUALS	0.1491D+01	-0.4271D-01	0.4068D+00
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.95803E+00	-0.12511E-01	-0.86967E-01
-0.12511E-01	0.94281E+00	0.73966E-01
-0.86967E-01	0.73966E-01	0.12417E+01

POINT NO. 9	X	Y	Z
	73.911	0.577	41.27[illegible]
STD. ERROR	0.1032D+01	0.1026D+01	0.1124D+01
RESIDUALS	-0.1711D+00	-0.2766D+00	-0.1049D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10658E+01	-0.64557E-02	-0.66833E-01
-0.64557E-02	0.10519E+01	0.39698E-01
-0.66833E-01	0.39698E-01	0.12633E+01

POINT NO. 10	X	Y	Z
	76.957	0.888	42.779

STD. ERROR	0.1032D+01	0.1025D+01	0.1123D+01
RESIDUALS	-0.2375D+00	-0.2584D+00	-0.3882D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10651E+01	-0.66205E-02	-0.70906E-01
-0.66205E-02	0.10499E+01	0.39823E-01
-0.70906E-01	0.39823E-01	0.12608E+01

POINT NO. 11	X	Y	Z
	71.883	48.205	47.994
STD. ERROR	0.5410D+01	0.2486D+01	0.1640D+02
RESIDUALS	0.1167D+01	-0.1754D+00	-0.1364D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.29273E+02	0.48811E+01	-0.79912E+02
0.48811E+01	0.61812E+01	-0.16295E+02
-0.79912E+02	-0.16295E+02	0.26988E+03

POINT NO. 12	X	Y	Z
	45.309	46.233	85.608
STD. ERROR	0.2868D+01	0.1948D+01	0.1073D+02
RESIDUALS	-0.1309D+01	-0.7330D+00	-0.8083D+00
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.82246E+01	0.14871E+01	-0.23379E+02
0.14871E+01	0.37946E+01	-0.71965E+01
-0.23379E+02	-0.71965E+01	0.11514E+03

POINT NO. 13	X	Y	Z
	75.905	66.542	46.194
STD. ERROR	0.1029D+01	0.1021D+01	0.1123D+01
RESIDUALS	0.8450D+00	0.5755D-01	0.2661D+00
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10586E+01	0.58175E-02	-0.73228E-01
0.58175E-02	0.10422E+01	-0.36206E-01

-0.73228E-01	-0.36206E-01	0.12610E+01

POINT NO. 14	X	Y	Z
	42.399	67.626	84.602
STD. ERROR	0.9733D+00	0.9689D+00	0.1121D+01
RESIDUALS	-0.2409D+01	-0.2860D+00	-0.5224D+00
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.94725E+00	0.95035E-02	-0.61582E-01
0.95035E-02	0.93885E+00	-0.66320E-01
-0.61582E-01	-0.66320E-01	0.12573E+01

POINT NO. 15	X	Y	Z
	12.037	34.159	61.477
STD. ERROR	0.2034D+01	0.2053D+01	0.1393D+02
RESIDUALS	0.2773D+01	0.2341D+01	0.1473D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.41377E+01	-0.32643E-02	0.11936E+00
-0.32643E-02	0.42139E+01	0.20057E+01
0.11936E+00	0.20057E+01	0.19409E+03

POINT NO. 16	X	Y	Z
	11.614	67.104	57.818
STD. ERROR	0.9975D+00	0.9990D+00	0.1131D+01
RESIDUALS	0.1236D+01	0.2764D+00	0.5229D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.99496E+00	0.47647E-02	0.16029E-02
0.47647E-02	0.99984E+00	-0.47902E-01
0.16029E-02	-0.47902E-01	0.12796E+01

POINT NO. 18	X	Y	Z
	36.319	66.752	72.719
STD. ERROR	0.1038D+01	0.1037D+01	0.1134D+01

RESIDUALS	-0.1987D+00	0.5580D+00	0.5105D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.10767E+01	0.36792E-02	-0.22781E-01
0.36792E-02	0.10744E+01	-0.29581E-01
-0.22781E-01	-0.29581E-01	0.12849E+01

POINT NO. 20	X	Y	Z
	40.094	10.383	24.128
STD. ERROR	0.3563D+01	0.3415D+01	0.2027D+02
RESIDUALS	-0.9639D+00	-0.3825D+00	-0.1278D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.12692E+02	-0.59516E+01	-0.51049E+02
-0.59518E+01	0.11659E+02	0.47175E+02
-0.51049E+02	0.47175E+02	0.41100E+03

COMPARATOR

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4,1,-0.729,-9.729,0.01
4,2,0.307,-9.952,0.01
4,3,0.88,-9.617,0.01
4,4,4.469,-7.942,0.01
4,5,4.962,-8.015,0.01
4,6,5.402,-7.605,0.01
4,7,11.041,-11.327,0.01
4,8,12.458,-11.473,0.01
4,9,13.575,-8.923,0.01
4,10,14.50,-8.992,0.01
4,11,14.570,1.833,0.01
4,12,11.7,2.224,0.01
4,13,14.799,6.008,0.01
4,14,13.295,8.719,0.01
4,15,0.475,-0.355,0.01
4,16,-0.205,8.224,0.01
4,18,5.275,5.872,0.01
4,20,4.926,-5.955,0.01
5,1,-13.867,-8.509,0.01
5,2,-13.199,-8.901,0.01
5,3,-12.168,-8.655,0.01
5,4,-6.325,-7.108,0.01
5,5,-5.703,-7.121,0.01
5,6,-5.286,-7.073,0.01
5,7,-3.989,-10.211,0.01
5,8,-2.780,-10.455,0.01
5,9,1.807,-7.975,0.01
5,10,2.615,-8.038,0.01
5,11,2.114,2.929,0.01
5,12,-3.919,3.377,0.01
5,13,2.326,7.215,0.01
5,14,-2.609,9.842,0.01
5,15,-13.153,0.375,0.01
5,16,-13.656,8.731,0.01
5,18,-6.005,6.585,0.01
5,20,-6.017,-5.15,0.01
1,1,1,1,13.21,0.81,51.74,0.01,0.01,0.01
2,2,2,2,16.81,0.29,51.45,0.01,0.01,0.01
3,3,3,3,18.32,0.81,59.26,0.00,0.00,0.00
4,4,4,4,36.63,0.25,21.47,0.01,0.01,0.01
5,5,5,5,38.16,0.25,21.47,0.00,0.00,0.00
6,6,6,6,39.31,0.81,23.38,0.01,0.01,0.01
7,7,7,7,45.53,0.09,33.83,0.01,0.01,0.01
8,8,8,8,57.64,0.05,85.16,0.01,0.01,0.01
9,9,9,9,73.74,0.85,41.25,0.01,0.01,0.01
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1,1,1,10,76.72,0.63,42.74,0.01,0.01,0.01
2,2,2,11,73.05,48.05,45.63,0.00,0.00,0.00
3,3,3,12,44.0,45.6,34.3,0.00,0.00,0.00
4,4,4,13,75.75,55.62,45.45,0.01,0.01,0.01
5,5,5,14,39.99,57.8[illegible],64.03,0.01,0.01,0.01      - SURVEY DATA
6,6,6,15,14.81,35.6,52.95,0.00,0.00,0.00
7,7,7,16,12.85,57.85,57.37,0.01,0.01,0.01
8,8,8,18,35.12,57.81,22.77,0.01,0.01,0.01
9,9,9,20,39.13,10.0,22.85,0.00,0.00,0.00
4,13.20,30.0,250.0,0.001,0.001,0.0001    } EXTERIOR ORIENTATION
5,71.0,30.0,250.0,0.001,0.001,0.0001     } ELEMENTS.
INPUT FOR THE FORTRAN BLOCK
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NUMBER OF PHOTOGRAPHS= 2

DEGREES OF FREEDOM=*****

UNIT STANDARD ERROR= 0.28135D+02

RESULTS
EXTERIOR ORIENTATION

PHOTO NO. 1	XO(CMS)	YO(CMS)	ZO(CMS)	KAPPA(RAD.)	PHI(RAD.)	OMEGA(RAD.)
	-17.347	37.020	249.471	0.859323D-01	-0.14441D+00	-0.835717D-02
STD. ERROR	0.6885D+01	0.7342D+01	0.4833D+01	0.2448D-01	0.1452D-01	0.3584D-01
RESIDUALS	0.3055D+02	-0.7020D+01	0.8262D+00	-0.8493D-01	0.1454D+00	0.8457D-02
WEIGHTS	0.000	0.000	0.000	0.000	0.000	0.000

VARIANCE /COVARIANCE MATRIX

0.47410E+02	0.82470E+00	0.80645E+01	0.21549E-02	0.23192E+00	-0.56897E-02
0.82470E+00	0.53903E+02	-0.31928E+01	-0.72974E-01	-0.98976E-04	-0.26009E+00
0.80645E+01	-0.31928E+01	0.23842E+02	0.80064E-02	0.71745E-01	0.21982E-01
0.21649E-02	-0.72974E-01	0.80064E-02	0.59936E-03	0.60621E-04	0.28160E-03
0.23192E+00	-0.98976E-04	0.71745E-01	0.50621E-04	0.41985E-02	-0.26847E-05
-0.55897E-02	-0.26009E+00	0.21982E-01	0.28160E-03	-0.26847E-05	0.12845E-02

PHOTO NO. 5	XO(CMS)	YO(CMS)	ZO(CMS)	KAPPA(RAD.)	PHI(RAD.)	OMEGA(RAD.)
	33.687	36.348	259.592	0.61123D-01	-0.41789D+00	-0.32183D-02
STD. ERROR	0.7349D+01	0.7634D+01	0.4745D+01	0.2353D-01	0.3572D-01	0.3675D-01
RESIDUALS	0.3231D+02	-0.6348D+01	-0.3592D+01	-0.0012D-01	0.418D+00	0.0318D-02
WEIGHTS	0.000	0.000	0.000	0.000	0.000	0.000

VARIANCE /COVARIANCE MATRIX

0.54007E+02	-0.69333E+00	0.19750E+01	0.57330E-02	0.26054E+00	0.44937E-02
-0.69333E+00	0.58281E+02	-0.36924E+01	0.61752E-02	-0.32021E-02	-0.27815E+00
0.19750E+01	-0.36924E+01	0.22522E+02	-0.62513E-03	0.10195E-01	0.24408E-01
0.57330E-02	0.61752E-02	-0.62513E-03	0.55355E-03	0.60383E-04	0.32837E-04
0.26054E+00	-0.32021E-02	0.10195E-01	0.60383E-04	0.42760E-02	0.24725E-04
0.44937E-02	-0.27815E+00	0.24408E-01	0.32837E-04	0.24725E-04	0.13515E-02

RESULTS

PHOTO COORDINATES

ALL WEIGHTS TAKEN AS 1000.0

PHOTO NO.	POINT NO.	X(MM)	Y(MM)	VX(MM)	VY(MM)
4	1	-0.729	-9.720	-0.7721D+00	-0.2470D+00
4	2	0.307	-9.952	-0.7894D+00	-0.2829D+00
4	3	0.630	-9.517	-0.2070D-02	-0.4437D-01
4	4	4.439	-7.942	0.6537D+01	0.3441D-01
4	5	4.952	-8.015	-0.5122D-02	-0.5424D-01
4	6	5.402	-7.305	0.8907D+00	0.0724D+00
4	7	11.041	-11.327	0.6456D+00	0.8629D-01
4	8	12.458	-11.473	-0.1535D+01	0.8114D+00
4	9	13.575	-8.923	0.3094D+00	0.8425D+00
4	10	14.500	-8.992	0.4266D+00	0.3576D+00
4	11	14.570	1.338	-0.4069D-02	-0.4214D-01
4	12	11.700	2.224	-0.7147D-04	-0.7639D-03
4	13	14.739	6.008	-0.1039D+01	-0.4160D+00
4	14	13.295	8.719	0.2642D+01	0.4534D+00
4	15	0.475	-0.355	0.2602D-02	0.0616D-01
4	16	-0.205	8.224	-0.1537D+01	-0.4021D+00
4	18	5.275	5.872	0.1907D+00	-0.8092D+00
4	20	4.926	-5.955	-0.4267D-02	-0.4122D-01
5	1	-13.857	-8.509	-0.5036D+00	-0.7454D-01
5	2	-13.199	-8.901	-0.7217D+00	-0.0054D+00
5	3	-12.158	-8.553	0.1092D-02	0.4471D-01
5	4	-6.325	-7.108	0.6144D+00	0.4311D+00
5	5	-5.703	-7.121	0.4911D-02	0.5400D-01
5	6	-5.286	-7.073	0.1070D+01	0.0187D+00
5	7	-3.989	-10.211	0.6566D+00	-0.8530D-01
5	8	-2.780	-10.455	-0.1622D+01	-0.5400D-01
5	9	1.807	-7.975	0.2018D+00	0.0951D+00
5	10	2.615	-8.038	0.2701D+00	0.0434D+00
5	11	2.114	2.929	0.0955D-02	0.4264D-01
5	12	-3.919	3.377	0.5461D-04	0.0642D-01
5	13	2.328	7.215	-0.4111D+01	0.4042D+00
5	14	-2.609	9.342	0.2433D+01	0.2108D+00
5	15	-13.453	0.375	-0.1977D-02	-0.0673D-01
5	16	-13.656	8.731	-0.1382D+01	-0.0318D+00
5	18	-6.005	6.585	0.1661D+00	-0.6448D+00
5	20	-6.017	-5.100	0.3368D-02	0.4180D-01

RESULTS

SURVEY COORDINATES

POINT NO. 1	X	Y	Z
	13.176	0.209	61.781
STD. ERROR	0.2794D+00	0.2794D+00	0.2812D+00
RESIDUALS	0.8354D-01	0.4114D-01	-0.6031D-04
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.76040E-01	-0.26752E-04	-0.11014E-04
-0.26752E-04	0.78053E-01	0.20728E-03
-0.11014E-04	0.20728E-03	0.79092E-01

POINT NO. 2	X	Y	Z
	16.770	0.274	64.151
STD. ERROR	0.2793D+00	0.2793D+00	0.2812D+00
RESIDUALS	0.3998D-01	0.4612D-01	-0.4463D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.78023E-01	-0.27763E-04	-0.32411E-04
-0.27763E-04	0.78031E-01	0.21370E-03
-0.32411E-04	0.21370E-03	0.79088E-01

POINT NO. 3	X	Y	Z
	17.171	-0.850	57.344
STD. ERROR	0.2488D+01	0.4029D+01	0.1590D+02
RESIDUALS	0.1149D+01	0.4150D+01	0.4916D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.61901E+01	-0.20022E+01	-0.97643E+01
-0.20022E+01	0.16229E+02	0.54327E+02
-0.97643E+01	0.54327E+02	0.26570E+03

POINT NO. 4	X	Y	Z
	36.657	0.205	21.172
STD. ERROR	0.2800D+00	0.2800D+00	0.2813D+00
RESIDUALS	-0.2733D-01	-0.6325D-02	-0.2404D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.78427E-01	-0.15109E-04	-0.79043E-04
-0.15109E-04	0.78418E-01	0.11343E-03
-0.79043E-04	0.11343E-03	0.79118E-01

POINT NO. 5	X	Y	Z
	42.336	0.445	14.388
STD. ERROR	0.4402D+01	0.4733D+01	0.2411D+02
RESIDUALS	-0.4175D+01	-0.2448D+00	0.4282D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.19376E+02	-0.12315E+02	-0.78677E+02
-0.12315E+02	0.22404E+02	0.89708E+02
-0.78677E+02	0.89708E+02	0.58151E+03

POINT NO. 6	X	Y	Z
	39.352	0.324	24.484
STD. ERROR	0.2800D+00	0.2800D+00	0.2813D+00
RESIDUALS	-0.4191D-01	-0.4386D-01	-0.2591D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.78418E-01 -0.15483E-04 -0.89292E-04

-0.15483E-04	0.78406E-01	0.11572E-03
-0.89292E-04	0.11572E-03	0.79114E-01

POINT NO. 7	X	Y	Z
	45.558	0.093	84.437
STD. ERROR	0.2791D+00	0.2793D+00	0.2811D+00
RESIDUALS	-0.3752D-01	-0.2302D-02	-0.6985D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.77871E-01	-0.38078E-04	-0.25421E-03
-0.38078E-04	0.77823E-01	0.27707E-03
-0.25421E-03	0.27707E-03	0.79006E-01

POINT NO. 8	X	Y	Z
	57.449	0.051	8[illegible].135
STD. ERROR	0.2791D+00	0.2759D+00	0.2811D+00
RESIDUALS	0.9356D-01	-0.5110D-03	0.0527D-01
WEIGHTS	10000.000	10000.000	10000.000

STD. ERROR	0.27990+00	0.27980+00	0.2811D+00
RESIDUALS	-0.14900-01	-0.45250-01	[illegible]
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.78360E-01	-0.19606E-04	-0.24418E-03
-0.19606E-04	0.78307E-01	0.13801E-03
-0.24418E-03	0.13801E-03	0.79949E-01

POINT NO. 11	X	Y	Z
	71.758	48.242	[illegible]
STD. ERROR	0.6181D+01	0.2818D+01	0.1875D+02
RESIDUALS	0.4282D+01	-0.2118D+00	[illegible]
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.36205E+02	0.59107E+01	-0.10431E+03
0.59107E+01	0.79433E+01	-0.19792E+02
-0.10431E+03	-0.19792E+02	0.35186E+03

POINT NO. 12	X	Y	Z
	45.191	45.430	85.426
STD. ERROR	0.3360D+01	0.2241D+01	0.1256D+02
RESIDUALS	-0.4191D+01	-0.9300D+00	-0.8261D+00
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.11292E+02	0.18953E+01	-0.32271E+02
0.18953E+01	0.50241E+01	-0.91093E+01
-0.32271E+02	-0.91093E+01	0.15769E+03

POINT NO. 13	X	Y	Z
	76.701	56.596	46.494
STD. ERROR	0.2799D+00	0.2798D+00	0.2811D+00
RESIDUALS	0.4935D-01	0.4131D-02	0.4594D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.78331E-01	0.15195E-04	-0.25878E-03
0.15195E-04	0.78272E-01	-0.12217E-03

-0.25878E-03	-0.12217E-03	0.79039E-01

POINT NO. 14	X	Y	Z
	40.135	57.364	84.111
STD. ERROR	0.2790D+00	0.2789D+00	0.2811D+00
RESIDUALS	-0.1455D+00	-0.2381D-01	-0.8096D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.77841E-01	0.30909E-04	-0.22236E-03
0.30909E-04	0.77796E-01	-0.23906E-03
-0.22236E-03	-0.23906E-03	0.79035E-01

POINT NO. 15	X	Y	Z
	11.883	34.185	61.224
STD. ERROR	0.2357D+01	0.2375D+01	0.1629D+02
RESIDUALS	0.2927D+01	0.2315D+01	0.4726D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.55556E+01	-0.34152E-01	-0.20619E+01
-0.34152E-01	0.56458E+01	0.33836E+01
-0.20619E+01	0.33836E+01	0.26233E+03

POINT NO. 16	X	Y	Z
	12.775	57.365	57.456
STD. ERROR	0.2794D+00	0.2794D+00	0.2813D+00
RESIDUALS	0.7547D-01	0.4492D-01	0.8954D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.78077E-01	0.22073E-04	-0.96636E-05
0.22073E-04	0.78087E-01	-0.16628E-03
-0.96636E-05	-0.16628E-03	0.79107E-01

POINT NO. 18	X	Y	Z
	36.131	57.276	22.757
STD. ERROR	0.2800D+00	0.2800D+00	0.2813D+00

RESIDUALS	-0.1072D-01	0.8217D-01	0.0425D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.78415E-01	0.12783E-04	-0.80183E-04
0.12783E-04	0.78403E-01	-0.97877E-04
-0.80183E-04	-0.97877E-04	0.79127E-01

POINT NO. 20	X	Y	Z
	40.281	10.337	24.490
STD. ERROR	0.4171D+01	0.3913D+01	0.2328D+02
RESIDUALS	-0.4151D+01	-0.3356D+01	-0.4[illegible]D+01
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.17399E+02	-0.80940E+01	-0.69829E+02
-0.80940E+01	0.15309E+02	0.61850E+02
-0.69829E+02	0.61850E+02	0.54210E+03

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         0000111111111112222222222333333333344444444445555555555666666666677777777778888888888999999999000
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
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EXPERIMENT 2

Plates V-3, V-4

INPUT DATA

Photo Coordinates

```
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11,2,8.776,-38.227,0.01
11,3,3.207,-16.503,0.01
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11,27,40.109,-0.415,0.01
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11,4 ,32.802,-13.935,0.01
11,41,36.843,-13.321,0.01
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Survey Data

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2,75.0,30.0,250.0,0.001,0.001,0.001
INPUT FOR THE FORTRAN BLOCK
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EXTERIOR ORIENTATION PARAMETERS

DEGREES OF FREEDOM=*****

PHOTO

JOB NUMBER 999

NUMBER OF PHOTOGRAPHS= 2

UNIT STANDARD ERROR= 0.38906D+02

RESULTS

EXTERIOR ORIENTATION

PHOTO NO.11	XO(METERS)	YO(METERS)	ZO(METERS)	KAPPA(RAD.)	PHI(RAD.)	OMEGA(RAD.)
	11.175	42.233	267.704	-0.813787D-01	-0.206884D-01	-0.648655D-01
STD. ERROR	0.2675D+01	0.2763D+01	0.1521D+01	0.7657D-02	0.1363D-01	0.1382D-01
RESIDUALS	0.3825D+01	-0.1223D+02	-0.1770D+02	0.8238D-01	0.2169D-01	0.6587D-01
WEIGHTS	0.000	0.000	0.000	0.000	0.000	0.000

VARIANCE /COVARIANCE MATRIX

0.71550E+01	0.53970E-02	0.87135E+00	-0.23352E-02	0.36228E-01	0.54660E-03
0.53970E-02	0.76355E+01	-0.91421E-01	-0.60301E-02	0.38602E-03	-0.37956E-01
0.87135E+00	-0.91421E-01	0.23130E+01	-0.11476E-03	0.62887E-02	0.16416E-02
-0.23352E-02	-0.60301E-02	-0.11476E-03	0.58624E-04	-0.10136E-04	0.22070E-04
0.36228E-01	0.38602E-03	0.62887E-02	-0.10136E-04	0.18573E-03	0.16540E-05
0.54660E-03	-0.37956E-01	0.16416E-02	0.22070E-04	0.16540E-05	0.19107E-03

PHOTO NO.12	XO(METERS)	YO(METERS)	ZO(METERS)	KAPPA(RAD.)	PHI(RAD.)	OMEGA(RAD.)
	65.284	45.718	265.328	-0.593741D-02	-0.271751D-01	-0.715179D-01
STD. ERROR	0.2551D+01	0.2637D+01	0.1474D+01	0.7375D-02	0.1342D-01	0.1349D-01
RESIDUALS	0.8716D+01	-0.1572D+02	-0.1533D+02	0.6937D-02	0.2818D-01	0.7252D-01
WEIGHTS	0.000	0.000	0.000	0.000	0.000	0.000

VARIANCE /COVARIANCE MATRIX

0.65100E+01	-0.11868E+00	-0.80496E+00	-0.24833E-02	0.33575E-01	0.10006E-03
-0.11868E+00	0.69528E+01	-0.18098E+00	0.28040E-02	-0.10158E-02	-0.35327E-01
-0.80496E+00	-0.18098E+00	0.21717E+01	0.17368E-03	-0.53841E-02	0.22742E-02
-0.24833E-02	0.28040E-02	0.17368E-03	0.54392E-04	-0.10359E-04	-0.66472E-05
0.33575E-01	-0.10158E-02	-0.53841E-02	-0.10359E-04	0.17466E-03	0.13805E-05
0.10006E-03	-0.35327E-01	0.22742E-02	-0.66472E-05	0.13805E-05	0.18202E-03

X (cm)	Y (cm)	Z (cm)
19.1103,	7.4019,	88.4376
17.8297,	12.2111,	46.6855
8.6733,	8.3567,	51.8790
65.1561,	-[illegible].3363,	88.4414
76.4773,	8.[illegible]526,	52.1498
69.2821,	11.6874,	48.0143
69.6113,	50.[illegible]351,	88.4314
68.0353,	53.6382,	57.1271
43.6457,	51.5315,	55.5760
21.8623,	59.1173,	57.3957
18.4903,	51.3173,	90.0392
43.2913,	18.8776,	58.1107
17.0564,	22.3124,	66.1298

143

[illegible]	[illegible]	[illegible]
[illegible]	31.9313,	76.1645
44.5121,	31.0220,	76.4317
47.2791,	33.5527,	74.9067
40.7713,	30.6896,	76.4843
44.3877,	30.2492,	77.8753
47.0093,	30.1459,	76.1790
39.1391,	26.1086,	67.2695
42.6478,	26.1825,	65.1659
46.7580,	26.4106,	64.6955
50.5300,	25.8545,	66.7518
36.6503,	25.4170,	79.7114
44.4113,	25.4584,	82.2574
52.6739,	21.4798,	80.1883
34.6881,	22.0094,	82.4850
44.6223,	22.5724,	85.7351
53.2826,	21.5031,	82.6856
31.4306,	16.7505,	80.4995
40.1201,	17.2231,	86.1501
44.8462,	17.4265,	86.8317
49.6844,	16.9611,	85.4389
56.5104,	16.2819,	79.5365
33.6035,	9.7203,	70.1598
42.7450,	8.9843,	69.4068
47.9424,	8.7390,	67.6766
54.9553,	10.2481,	71.8841
36.7517,	7.4896,	79.5757
44.4527,	7.2366,	81.8779
51.5719,	7.9178,	78.8566
40.1161,	1.9781,	73.9227
47.0947,	1.6522,	73.7571

RESULTS
PHOTO COORDINATES
ALL WEIGHT S TAKEN AS 1000.0

PHOTO NO.	POINT NO.	X(MM)	Y(MM)	VX(MM)	VY(MM)
11	2	8.776	-38.227	-0.9012D-02	-0.1955D+00
11	3	3.207	-16.503	-0.3022D+00	-0.3014D+00
11	4	-5.877	-21.683	-0.1996D+00	-0.2024D+00
11	5	65.967	-33.531	-0.1548D+00	-0.4643D+00
11	7	66.468	-16.016	0.1008D+01	-0.1126D+00
11	8	57.196	-12.427	0.6623D+00	-0.1647D+00
11	9	67.613	29.847	-0.2407D+00	-0.6246D+00
11	10	52.782	37.026	-0.1822D+01	-0.3811D+00
11	11	28.072	35.540	0.2303D+00	0.4859D+00
11	12	4.657	33.686	0.4265D+00	-0.6530D+00
11	13	3.365	25.512	0.6675D+00	0.9917D-01
11	14	28.580	25.152	-0.4802D-01	0.5341D+00
11	15	2.545	-7.538	0.3101D-02	-0.1721D-01
11	16	62.888	-3.525	0.2119D-01	-0.1910D+00
11	18	30.853	7.879	-0.3836D-01	0.4373D+00
11	19	34.669	8.038	-0.1198D-01	0.1579D+00
11	20	37.616	7.796	-0.1210D-01	0.1578D+00
11	21	30.468	3.770	-0.1941D-01	0.2318D+00
11	22	35.110	3.422	-0.1070D-01	0.1392D+00
11	23	38.816	3.731	-0.1096D-01	0.1415D+00
11	24	27.303	-0.751	-0.1940D-01	0.2140D+00
11	25	30.893	-0.316	-0.4150D-01	0.4318D+00
11	26	35.347	0.784	-0.8288D-01	0.8649D+00
11	27	40.109	-0.415	-0.8675D-02	0.9676D-01
11	28	26.574	-3.297	-0.1153D-01	0.1393D+00
11	30	36.505	-2.637	-0.1743D-01	0.2010D+00
11	32	46.149	-3.279	0.2598D-01	-0.2547D+00
11	33	24.961	-7.971	-0.6936D-02	0.1024D+00
11	35	37.860	-6.936	0.1967D-01	-0.1846D+00
11	37	47.827	-7.050	0.2170D-01	-0.2107D+00
11	38	21.157	-14.414	-0.7863D-02	0.1039D+00
11	40	32.802	-13.935	0.6518D-02	-0.1190D-01
11	41	38.843	-13.321	0.1302D-01	-0.3654D-01
11	42	44.551	-13.412	0.2316D-01	-0.2595D+00
11	44	51.223	-12.582	0.1626D-01	-0.1519D+00
11	45	22.793	-20.233	-0.5761D-01	0.6005D+00
11	47	33.213	-20.539	-0.1140D-01	0.1255D+00
11	48	38.780	-20.204	0.5970D-02	-0.5484D-01
11	50	47.687	-18.595	0.1245D-01	-0.1185D+00
11	51	28.261	-25.047	0.1208D-01	-0.1233D+00
11	53	38.043	-25.013	0.8870D-02	-0.8869D-01
11	55	45.789	-22.904	0.1389D-01	-0.1238D+00
11	56	31.638	-29.750	-0.5792D-02	0.7311D-01
11	58	39.754	-29.623	0.1494D-01	-0.1360D+00
12	2	-65.809	-42.672	0.6476D+00	0.2198D+00
12	3	-57.069	-20.105	0.4191D+00	-0.7566D+00
12	4	-67.349	-25.486	0.7219D+00	-0.1423D+01
12	5	-7.830	-41.865	-0.3854D+00	0.3948D+00
12	7	5.470	-24.445	0.6986D+00	-0.6494D+00
12	8	-2.924	-20.194	0.6547D-01	-0.8547D+00
12	9	-3.165	21.998	-0.1133D+01	-0.1142D+00

Ph.No	point	X(mm)	Y(mm)	VX(mm)	VY(mm)
12	10	-6.943	30.392	-0.2458D+01	-0.4710D+00
12	11	-31.805	29.851	-0.2862D+00	-0.7137D+00
12	12	-55.735	39.346	0.5239D+00	0.7703D+01
12	13	-68.723	21.255	0.1155D+01	-0.7004D+00
12	14	-32.060	19.361	0.1465D-01	-0.5214D+00
12	15	-63.114	-10.847	-0.1122D-03	0.2606D-01
12	16	-7.041	-11.453	-0.2111D-03	0.2006D+00
12	18	-36.587	1.458	0.1162D-01	-0.4231D+00
12	19	-32.781	1.894	0.5668D-02	-0.1435D+00
12	20	-29.242	1.451	0.6019D-02	-0.1461D+00
12	21	-37.342	-2.264	0.7326D-02	-0.2191D+00
12	22	-33.109	-2.820	0.5706D-02	-0.1270D+00
12	23	-28.693	-2.751	0.6355D-02	-0.1300D+00
12	24	-37.727	-6.357	0.9545D-02	-0.2044D+00
12	25	-33.343	-6.559	0.1647D-01	-0.4214D+00
12	26	-28.553	-6.657	0.2440D-01	-0.8535D+00
12	27	-24.453	-6.732	0.7468D-02	-0.8797D-01
12	28	-42.902	-9.033	0.6299D-02	-0.1280D+00
12	30	-33.628	-9.313	0.9126D-02	-0.1692D+00
12	32	-23.050	-9.723	-0.5033D-03	0.2025D+00
12	33	-45.859	-13.652	0.2441D-02	-0.9083D-01
12	35	-33.842	-13.097	-0.3185D-02	0.1945D+00
12	37	-22.470	-13.830	0.5866D-03	0.2186D+00
12	38	-49.378	-19.844	0.3896D-02	-0.9391D-01
12	40	-39.579	-20.166	-0.2777D-02	0.2677D-01
12	41	-33.623	-19.933	-0.3756D-03	0.8965D-01
12	42	-27.238	-20.012	-0.3730D-02	0.2660D+00
12	44	-18.147	-19.721	0.4549D-02	0.1595D+00
12	45	-44.383	-26.582	0.1968D-01	-0.5885D+00
12	47	-33.529	-26.703	0.8379D-02	-0.1179D+00
12	48	-27.272	-26.377	0.4123D-02	0.6077D-01
12	50	-19.454	-25.401	0.4445D-02	0.1243D+00
12	51	-42.379	-30.670	-0.3678D-02	0.1299D+00
12	53	-33.202	-31.510	0.8281D-03	0.9486D-01
12	55	-24.050	-29.799	0.5250D-02	0.1293D+00
12	56	-37.183	-35.930	0.6660D-02	-0.6720D-01
12	58	-28.833	-35.975	0.3251D-02	0.1397D+00

RESULTS
SURVEY COORDINATES

POINT NO. 2	X	Y	Z
	19.411	0.002	86.458
STD. ERROR	0.3377D+00	0.3398D+00	0.3842D+00
RESIDUALS	-0.8089D-01	-0.8524D-03	0.2243D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.11404E+00	0.35610E-03	0.41200E-02
0.35610E-03	0.11544E+00	0.87127E-02
0.41200E-02	0.87127E-02	0.14758E+00

POINT NO. 3	X	Y	Z
	17.830	12.210	48.686
STD. ERROR	0.3520D+00	0.3527D+00	0.3873D+00
RESIDUALS	-0.9669D-02	0.1096D+00	-0.5509D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.12389E+00	0.18957E-03	0.26959E-02
0.18957E-03	0.12442E+00	0.38722E-02
0.26959E-02	0.38722E-02	0.15000E+00

POINT NO. 4

	X	Y	Z
	8.674	8.367	51.899
STD. ERROR	0.3511D+00	0.3519D+00	0.3866D+00
RESIDUALS	-0.5360D-01	0.1733D+00	-0.8996D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.12324E+00	0.29992E-03	0.39784E-02
0.29992E-03	0.12386E+00	0.44771E-02
0.39784E-02	0.44771E-02	0.14948E+00

POINT NO. 5

	X	Y	Z
	65.156	-0.006	88.444
STD. ERROR	0.3388D+00	0.3402D+00	0.3839D+00
RESIDUALS	0.7359D-01	0.7302D-02	0.5646D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.11478E+00	-0.66914E-03	-0.50594E-02
-0.66914E-03	0.11576E+00	0.85906E-02
-0.50594E-02	0.85906E-02	0.14740E+00

POINT NO. 7

	X	Y	Z
	76.477	8.063	52.150
STD. ERROR	0.3520D+00	0.3524D+00	0.3864D+00
RESIDUALS	-0.1773D+00	0.8741D-01	-0.4980D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.12391E+00	-0.44698E-03	-0.46573E-02
-0.44698E-03	0.12415E+00	0.44439E-02
-0.46573E-02	0.44439E-02	0.14928E+00

POINT NO. 8

	X	Y	Z
	59.282	11.687	48.014
STD. ERROR	0.3529D+00	0.3533D+00	0.3870D+00
RESIDUALS	-0.7207D-01	0.1126D+00	-0.3432D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.12457E+00	-0.33040E-03	-0.36034E-02
-0.33040E-03	0.12481E+00	0.38447E-02
-0.36034E-02	0.38447E-02	0.14980E+00

POINT NO. 9	X	Y	Z
	59.615	50.035	88.431
STD. ERROR	0.3375D+00	0.3364D+00	0.3861D+00
RESIDUALS	0.1851D+00	0.9490D-01	0.1860D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.11388E+00	-0.18463E-03	-0.62767E-02
-0.18463E-03	0.11317E+00	-0.13692E-02
-0.62767E-02	-0.13692E-02	0.14909E+00

POINT NO. 10	X	Y	Z
	68.035	58.638	57.127
STD. ERROR	0.3492D+00	0.3485D+00	0.3874D+00
RESIDUALS	0.4747D+00	0.8178D-01	0.6285D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.12196E+00	-0.75358E-04	-0.39992E-02
-0.75358E-04	0.12142E+00	-0.21274E-02
-0.39992E-02	-0.21274E-02	0.15005E+00

POINT NO. 11	X	Y	Z
	43.647	58.531	55.576
STD. ERROR	0.3492D+00	0.3488D+00	0.3861D+00
RESIDUALS	0.3270D-02	0.2851D-01	-0.5952D-02
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.12194E+00	0.64830E-04	-0.56870E-03
0.64830E-04	0.12164E+00	-0.20713E-02
-0.56870E-03	-0.20713E-02	0.15059E+00

POINT NO. 12	X	Y	Z

	X	Y	Z
	21.862	59.417	57.396
STD. ERROR	0.3483D+00	0.3480D+00	0.3877D+00
RESIDUALS	-0.1023D+00	-0.7873D+00	-0.4571D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.12131E+00	0.19471E-03	0.25487E-02
0.19471E-03	0.12108E+00	-0.22761E-02
0.25487E-02	-0.22761E-02	0.15033E+00

POINT NO. 13	X	Y	Z
	18.491	50.047	90.039
STD. ERROR	0.3353D+00	0.3350D+00	0.3866D+00
RESIDUALS	-0.2408D+00	0.9269D-01	0.4076D-01
WEIGHTS	10000.000	10000.000	10000.000

VARIANCE/COVARIANCE MATRIX

0.11244E+00	0.28073E-03	0.46526E-02
0.28073E-03	0.11225E+00	-0.14263E-02
0.46526E-02	-0.14263E-02	0.14948E+00

POINT NO. 14	X	Y	Z
	43.294	48.878	58.111
STD. ERROR	0.7921D+00	0.7954D+00	0.5932D+01
RESIDUALS	0.5712D-02	-0.5599D-02	0.3893D+00
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.62748E+00	0.16489E-01	-0.63720E+00
0.16489E-01	0.63263E+00	-0.86337E+00
-0.63720E+00	-0.86337E+00	0.35189E+02

POINT NO. 15	X	Y	Z
	17.057	22.342	66.130
STD. ERROR	0.9748D+00	0.9511D+00	0.5469D+01
RESIDUALS	-0.2268D+00	-0.1924D+00	-0.3298D+00
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.95019E+00	0.36322E+00	0.33609E+01

0.36322E+00	0.92368E+00	0.31957E+01
0.33609E+01	0.31957E+01	0.29912E+02

POINT NO. 16	X	Y	Z
	65.600	23.395	83.176
STD. ERROR	0.9563D+00	0.8742D+00	0.4680D+01
RESIDUALS	-0.9531D-04	0.1171D-01	0.3240D+00
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.93366E+00	-0.35081E+00	-0.31128E+01
-0.35081E+00	0.76418E+00	0.24332E+01
-0.31128E+01	0.24332E+01	0.21905E+02

POINT NO. 18	X	Y	Z
	41.392	33.901	76.165
STD. ERROR	0.7218D+00	0.7660D+00	0.4969D+01
RESIDUALS	-0.4103D+02	-0.3354D+02	-0.7580D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.52097E+00	-0.12076E-01	-0.23515E+00
-0.12076E-01	0.58671E+00	0.12777E+01
-0.23515E+00	0.12777E+01	0.24695E+02

POINT NO. 19	X	Y	Z
	44.542	34.022	76.432
STD. ERROR	0.7314D+00	0.7642D+00	0.4962D+01
RESIDUALS	-0.4418D+02	-0.3366D+02	-0.7607D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.53468E+00	-0.33433E-01	-0.64362E+00
-0.33433E-01	0.58399E+00	0.12604E+01
-0.64362E+00	0.12604E+01	0.24625E+02

POINT NO. 20	X	Y	Z
	47.278	33.553	74.907

STD. ERROR	0.7541D+00	0.7751D+00	0.5049D+01
RESIDUALS	-0.4692D+02	-0.3319D+02	-0.7455D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.56862E+00	-0.55700E-01	-0.10267E+01
-0.55700E-01	0.60077E+00	0.13574E+01
-0.10267E+01	0.13574E+01	0.25494E+02

POINT NO. 21	X	Y	Z
	40.771	30.690	76.484
STD. ERROR	0.7204D+00	0.7983D+00	0.4957D+01
RESIDUALS	-0.4041D+02	-0.3033D+02	-0.7612D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.51900E+00	-0.10605E-01	-0.15423E+00
-0.10605E-01	0.63724E+00	0.16886E+01
-0.15423E+00	0.16886E+01	0.24569E+02

POINT NO. 22	X	Y	Z
	44.388	30.249	77.675
STD. ERROR	0.7261D+00	0.7982D+00	0.4893D+01
RESIDUALS	-0.4403D+02	-0.2989D+02	-0.7752D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.52718E+00	-0.44423E-01	-0.61072E+00
-0.44423E-01	0.63711E+00	0.17138E+01
-0.61072E+00	0.17138E+01	0.23945E+02

POINT NO. 23	X	Y	Z
	47.810	30.146	76.179
STD. ERROR	0.7540D+00	0.8071D+00	0.4989D+01
RESIDUALS	-0.4745D+02	-0.2979D+02	-0.7582D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.56848E+00	-0.78490E-01	-0.10787E+01
-0.78490E-01	0.65144E+00	0.17799E+01
-0.10787E+01	0.17799E+01	0.24894E+02

POINT NO. 24	X	Y	Z
	39.139	26.409	67.269
STD. ERROR	0.7554D+00	0.8950D+00	0.5452D+01
RESIDUALS	-0.3889D+02	-0.3209D+01	-0.6691D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.57062E+00	0.52466E-02	0.59598E-01
0.52466E-02	0.80101E+00	0.25882E+01
0.59598E-01	0.25882E+01	0.29719E+02

POINT NO. 25	X	Y	Z
	42.648	26.182	65.166
STD. ERROR	0.7688D+00	0.9085D+00	0.5576D+01
RESIDUALS	-0.4240D+02	0.3012D+02	-0.4157D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.59110E+00	-0.42774E-01	-0.48240E+00
-0.42774E-01	0.82541E+00	0.27147E+01
-0.48240E+00	0.27147E+01	0.31089E+02

POINT NO. 26	X	Y	Z
	46.759	26.411	64.695
STD. ERROR	0.7924D+00	0.9079D+00	0.5611D+01
RESIDUALS	-0.4640D+02	-0.2605D+02	-0.6434D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.62795E+00	-0.98652E-01	-0.11302E+01
-0.98652E-01	0.82434E+00	0.27077E+01
-0.11302E+01	0.27077E+01	0.31485E+02

POINT NO. 27	X	Y	Z
	50.501	25.855	66.752
STD. ERROR	0.8177D+00	0.9080D+00	0.5508D+01
RESIDUALS	-0.2520D+02	-0.5545D+00	-0.4145D+02

WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.66857E+00	-0.15183E+00	-0.16683E+01
-0.15183E+00	0.82450E+00	0.27201E+01
-0.16683E+01	0.27201E+01	0.30334E+02

POINT NO. 28	X	Y	Z
	36.650	25.417	79.711
STD. ERROR	0.7122D+00	0.8532D+00	0.4790D+01
RESIDUALS	-0.1440D+02	0.1830D+00	-0.5411D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.50722E+00	0.35885E-01	0.36163E+00
0.35885E-01	0.72800E+00	0.22510E+01
0.36163E+00	0.22510E+01	0.22942E+02

POINT NO. 30	X	Y	Z
	44.411	25.468	82.257
STD. ERROR	0.7106D+00	0.8425D+00	0.4677D+01
RESIDUALS	-0.2081D+02	-0.1868D+01	-0.5866D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.50494E+00	-0.57810E-01	-0.57240E+00
-0.57810E-01	0.70982E+00	0.21702E+01
-0.57240E+00	0.21702E+01	0.21876E+02

POINT NO. 32	X	Y	Z
	52.674	24.480	80.186
STD. ERROR	0.7859D+00	0.8584D+00	0.4802D+01
RESIDUALS	-0.1617D+02	0.8120D+01	-0.5659D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.61765E+00	-0.17050E+00	-0.16228E+01
-0.17050E+00	0.75415E+00	0.23856E+01
-0.16228E+01	0.23856E+01	0.23061E+02

POINT NO. 33	X	Y	Z
	34.688	22.009	82.485
STD. ERROR	0.7092D+00	0.8923D+00	0.4650D+01
RESIDUALS	-0.9388D+01	-0.9709D+01	-0.6818D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.50299E+00	0.68788E-01	0.57800E+00
0.68788E-01	0.79618E+00	0.25536E+01
0.57800E+00	0.25536E+01	0.21624E+02

POINT NO. 35	X	Y	Z
	44.622	22.572	85.735
STD. ERROR	0.6989D+00	0.8701D+00	0.4508D+01
RESIDUALS	-0.1902D+02	0.1028D+01	-0.7344D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.48852E+00	-0.67335E-01	-0.56435E+00
-0.67335E-01	0.75713E+00	0.23800E+01
-0.56435E+00	0.23800E+01	0.20322E+02

POINT NO. 37	X	Y	Z
	53.282	21.503	82.686
STD. ERROR	0.7832D+00	0.9041D+00	0.4681D+01
RESIDUALS	-0.1698D+02	0.1480D+02	-0.4639D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.61336E+00	-0.20079E+00	-0.16348E+01
-0.20079E+00	0.81736E+00	0.26524E+01
-0.16348E+01	0.26524E+01	0.21914E+02

POINT NO. 38	X	Y	Z
	31.431	16.751	80.500
STD. ERROR	0.7367D+00	0.9921D+00	0.4752D+01
RESIDUALS	0.4869D+01	0.1955D+02	-0.4420D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.54268E+00	0.14472E+00	0.99166E+00
0.14472E+00	0.98422E+00	0.32772E+01
0.99166E+00	0.32772E+01	0.22583E+02

POINT NO. 40	X	Y	Z
	40.120	17.223	86.156
STD. ERROR	0.6868D+00	0.9564D+00	0.4486D+01
RESIDUALS	0.5180D+01	-0.1923D+01	-0.7385D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.47163E+00	-0.91944E-02	-0.57294E-01
-0.91944E-02	0.91464E+00	0.29593E+01
-0.57294E-01	0.29593E+01	0.20127E+02

POINT NO. 41	X	Y	Z
	44.846	17.427	86.832
STD. ERROR	0.6972D+00	0.9506D+00	0.4462D+01
RESIDUALS	0.1145D+02	0.5673D+01	-0.8647D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.48602E+00	-0.86760E-01	-0.58135E+00
-0.86760E-01	0.90361E+00	0.29165E+01
-0.58135E+00	0.29165E+01	0.19912E+02

POINT NO. 42	X	Y	Z
	49.684	16.961	85.439
STD. ERROR	0.7361D+00	0.9676D+00	0.4542D+01
RESIDUALS	-0.4932D+02	-0.1660D+02	-0.8508D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.54188E+00	-0.17282E+00	-0.11511E+01
-0.17282E+00	0.93625E+00	0.30526E+01
-0.11511E+01	0.30526E+01	0.20634E+02

POINT NO. 44

	X	Y	Z
	56.511	16.282	79.537
STD. ERROR	0.8398D+00	0.1013D+01	0.4858D+01
RESIDUALS	-0.5615D+02	-0.1592D+02	-0.7918D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.70532E+00	-0.31863E+00	-0.21414E+01
-0.31863E+00	0.10271E+01	0.34677E+01
-0.21414E+01	0.34677E+01	0.23596E+02

POINT NO. 45

	X	Y	Z
	33.604	9.720	70.160
STD. ERROR	0.7648D+00	0.1191D+01	0.5311D+01
RESIDUALS	-0.3324D+02	-0.9360D+01	-0.6980D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.58487E+00	0.14787E+00	0.85301E+00
0.14787E+00	0.14191E+01	0.48894E+01
0.85301E+00	0.48894E+01	0.28204E+02

POINT NO. 47

	X	Y	Z
	42.745	8.984	59.409
STD. ERROR	0.7575D+00	0.1215D+01	0.5374D+01
RESIDUALS	-0.4238D+02	-0.8624D+01	-0.6905D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.57383E+00	-0.85234E-01	-0.47241E+00
-0.85234E-01	0.14768E+01	0.50958E+01
-0.47241E+00	0.50958E+01	0.28877E+02

POINT NO. 48

	X	Y	Z
	47.942	8.739	67.677
STD. ERROR	0.7947D+00	0.1233D+01	0.5481D+01
RESIDUALS	-0.4758D+02	-0.8379D+01	-0.6732D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.63162E+00	-0.22755E+00	-0.12748E+01

-0.22755E+00	0.15209E+01	0.52922E+01
-0.12748E+01	0.52922E+01	0.30038E+02

POINT NO. 50	X	Y	Z
	54.955	10.248	71.884
STD. ERROR	0.8542D+00	0.1178D+01	0.5266D+01
RESIDUALS	-0.5450D+02	-0.9888D+01	-0.7152D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.72970E+00	-0.38332E+00	-0.22014E+01
-0.38332E+00	0.13870E+01	0.47770E+01
-0.22014E+01	0.47770E+01	0.27735E+02

POINT NO. 51	X	Y	Z
	36.752	7.490	79.576
STD. ERROR	0.7170D+00	0.1182D+01	0.4826D+01
RESIDUALS	-0.3639D+02	-0.7130D+01	-0.7924D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.51415E+00	0.67394E-01	0.35145E+00
0.67394E-01	0.13977E+01	0.45181E+01
0.35145E+00	0.45181E+01	0.23292E+02

POINT NO. 53	X	Y	Z
	44.453	7.237	81.878
STD. ERROR	0.7171D+00	0.1176D+01	0.4726D+01
RESIDUALS	-0.4409D+02	-0.6877D+01	-0.8152D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.51425E+00	-0.11914E+00	-0.59106E+00
-0.11914E+00	0.13836E+01	0.44171E+01
-0.59106E+00	0.44171E+01	0.22333E+02

POINT NO. 55	X	Y	Z
	51.572	7.918	78.851

STD. ERROR	0.7842D+00	0.1184D+01	0.4896D+01
RESIDUALS	-0.5121D+02	-0.7558D+01	-0.7649D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.61502E+00	-0.29708E+00	-0.15367E+01
-0.29708E+00	0.14012E+01	0.45777E+01
-0.15367E+01	0.45777E+01	0.23967E+02

POINT NO. 56	X	Y	Z
	40.116	1.978	73.923
STD. ERROR	0.7369D+00	0.1342D+01	0.5138D+01
RESIDUALS	-0.3976D+02	-0.1618D+01	-0.7356D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.54296E+00	-0.19089E-01	-0.79615E-01
-0.19089E-01	0.17996E+01	0.57268E+01
-0.79615E-01	0.57268E+01	0.26396E+02

POINT NO. 58	X	Y	Z
	47.095	1.652	73.757
STD. ERROR	0.7660D+00	0.1353D+01	0.5163D+01
RESIDUALS	-0.4073D+02	-0.1292D+01	-0.7340D+02
WEIGHTS	0.000	0.000	0.000

VARIANCE/COVARIANCE MATRIX

0.58680E+00	-0.23204E+00	-0.10474E+01
-0.23204E+00	0.18317E+01	0.58238E+01
-0.10474E+01	0.58238E+01	0.26655E+02

APPENDIX C

C-1 COLLINEARITY CONDITION EQUATIONS AND THEIR APPLICATION IN BUNDLE ADJUSTMENT

In article III-3 the basic collinearity conditions equations are given and in V-2.4, some details of the linearised form of these equations are given. This article is intended to give more details about the same. For convenience the equations are rewritten here

$$x_o = -f\left[\frac{m_{11}(X_A - X_L) + m_{12}(Y_A - Y_L) + m_{13}(Z_A - Z_L)}{m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L)}\right] \quad (C\text{-}1.1)$$

$$y_a = -f\left[\frac{m_{21}(X_A - X_L) + m_{22}(Y_A - Y_L) + m_{23}(Z_A - Z_L)}{m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L)}\right] \quad (C\text{-}1.2)$$

where

x_a, y_a	=	photo-coordinates of the image points
X_A, Y_A, Z_A	=	ground-coordinates of the point A
X_L, Y_L, Z_L	=	ground-coordinates of the exposure station
f	=	camera constant or calibrated focal length
m_{11}	=	$\cos \phi \cdot \cos k$
m_{12}	=	$\sin w \ \sin \phi \ \cos k + \cos w \ \sin k$
m_{13}	=	$-\cos w \ \sin\phi \cos k + \sin w \sin k$
m_{21}	=	$-\cos\phi \sin k$
m_{22}	=	$-\sin w \sin\phi \sin k + \cos w \cos k$
m_{23}	=	$\cos w \sin\phi \sin k + \sin w \cos k$
m_{31}	=	$\sin\phi$
m_{32}	=	$-\sin w \cos\phi$
m_{33}	=	$\cos w \cos\phi$

k = rotation about Z axis (kappa)

w = rotation about X axis (omega)

$\emptyset$ = rotation about Y axis (Phi)

The above collinearity equations (C-1.1) and (C-1.2) are nonlinear and they have nine unknowns; the three rotation elements omega, phi and kappa (inherent in m's), the three exposure station coordinates X_L, Y_L and Z_L; the three object point coordinates X_A, Y_A and Z_A. To be used in least square methods the above equations are to be linearised using Taylor's theorem.

Equations (C-1.1) and (C-1.2) may be written as

$$F = 0 = q\, x_a + rf \tag{C-1.3}$$

$$G = 0 = q\, y_a + sf \tag{C-1.4}$$

where

$$q = m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L)$$

$$r = m_{11}(X_A - X_L) + m_{12}(Y_A - Y_L) + m_{13}(Z_A - Z_L)$$

$$s = m_{21}(X_A - X_L) + m_{22}(Y_A - Y_L) + m_{23}(Z_A - Z_L)$$

By Taylor's theorem equations (C-1.3) and (C-1.4) may be written as

$$0 = (F)_o + \left(\frac{\partial F}{\partial x_a}\right)_o dx_o + \left(\frac{\partial F}{\partial w}\right)_o dw + \left(\frac{\partial F}{\partial \emptyset}\right)_o d\emptyset$$

$$+ \left(\frac{\partial F}{\partial k}\right)_o dk + \left(\frac{\partial F}{\partial X_L}\right)_o dX_L + \left(\frac{\partial F}{\partial Y_L}\right)_o dY_L$$

$$+ \left(\frac{\partial F}{\partial Z_L}\right)_o dZ_L + \left(\frac{\partial F}{\partial X_A}\right)_o dX_A + \left(\frac{\partial F}{\partial Y_A}\right)_o dY_A$$

$$+ \left(\frac{\partial F}{\partial Z_A}\right)_o dZ_A \qquad \text{(C-1.5)}$$

$$O = (G)_o + \left(\frac{\partial G}{\partial y_a}\right)_o dy_a + \left(\frac{\partial G}{\partial g}\right)_o dw + \left(\frac{\partial G}{\partial \emptyset}\right)_o d\emptyset$$

$$+ \left(\frac{\partial G}{\partial k}\right)_k dk + \left(\frac{\partial G}{\partial X_L}\right)_o dX_L + \left(\frac{\partial G}{\partial Y_L}\right)_o dY_L$$

$$+ \left(\frac{\partial G}{\partial Z_L}\right)_o dZ_L + \left(\frac{\partial G}{\partial X_A}\right)_o dX_A + \left(\frac{\partial G}{\partial Y_A}\right)_o dY_A$$

$$+ \left(\frac{\partial G}{\partial Z_A}\right)_o dZ_A \qquad \text{(C-1.6)}$$

In the above equations $(F)_o$ and $(G)_o$ are the functions F and G of equations (C-1.3) and (C-1.4) evaluated at the initial approximations for the nine unknowns; the terms $(\partial F/\partial x_a)_o$, $(\partial F/\partial w)_o$, $(\partial F/\partial \emptyset)_o$ are the partial derivatives of the functions F and G with respect to the indicated unknowns evaluated at the initial approximations; and dw, dk, d$\emptyset$, etc. are the unknown corrections to be applied to the initial approximations. The units of dw, d$\emptyset$ and dk are radians. Since dx_a and dy_a are the corrections to the measured photo-coordinates x_a and y_a,

they may be considered as the residual errors in measurements. Hence these two terms may be replaced by v_{x_a} and v_{y_a} which are the usual notations for residual errors. $\partial F/\partial x_a$ and $\partial G/\partial y_a$ are equal to q. Substituting q, for these terms in the equations (C-1.5) and (C-1.6), transposing qdx_a and qdy_a to the left hand side of the equations, dividing each equation by q and replacing dx_a and dy_a by v_{x_a} and v_{y_a}

$$\begin{aligned} v_{x_a} = {} & b_{11}(dw) + b_{12}(d\emptyset) + b_{13}(dk) - b_{14}(dX_L) \\ & - b_{15}(dY_L) - b_{16}(dZ_L) + b_{14}(dX_A) \\ & + b_{15}(dY_A) + b_{16}(dZ_A) + J \end{aligned} \tag{C-1.7}$$

$$\begin{aligned} v_{y_a} = {} & b_{21}(dw) + b_{22}(d\emptyset) + b_{23}(dk) - b_{24}(dX_L) \\ & - b_{25}(dY_L) - b_{26}(dZ_L) + b_{24}(dX_A) \\ & + b_{25}(dY_A) + b_{26}(dZ_A) + K \end{aligned} \tag{C-1.8}$$

which are nothing but the basic observation equations used in Bundle Adjustment method.

In the above equations (C-1.7) and (C-1.8)

$$J = (F)_o/q$$

$$K = (G)_o/q$$

$$b_{11} = \frac{x}{q}(-m_{33}\Delta Y + m_{32}\Delta Z) + \frac{1}{q}(m_{13}\Delta Y + m_{12}\Delta Z)$$

$$b_{12} = \frac{x}{q}\left[\Delta X \cos\varnothing + \Delta Y (\sin w.\ \sin\varnothing) + \Delta Z (-\sin\varnothing \cos w)\right]$$

$$+ \frac{f}{q}[\Delta X (-\sin\varnothing \cos k) + \Delta Y (\sin w \cos\varnothing \cos k)$$

$$+ \Delta Z (-\cos w . \cos\varnothing \cos k)]$$

$$b_{13} = \frac{f}{q} (m_{21} \Delta X + m_{22} \Delta Y + m_{23} \Delta Z)$$

$$b_{14} = \frac{x}{q} (m_{31}) + \frac{f}{q} (m_{11})$$

$$b_{15} = \frac{x}{q} (m_{32}) + \frac{f}{q} (m_{12})$$

$$b_{16} = \frac{x}{q} (m_{33}) + \frac{f}{q} (m_{13})$$

$$J = \frac{(qx + rf)}{q}$$

$$b_{21} = \frac{y}{q} (-m_{33} \Delta Y + m_{32} \Delta Z)$$

$$+ \frac{f}{q} (- m_{23} \Delta Y + m_{22} \Delta Z)$$

$$b_{22} = \frac{y}{q}[\Delta X \cos\varnothing + \Delta Y (\sin w \sin\varnothing)$$

$$+ \Delta Z (-\cos w \sin\varnothing)]$$

$$+ \frac{f}{q}[\Delta X (\sin\varnothing . \sin k) + \Delta Y (-\sin w \cos\varnothing \sin k)$$

$$+ \Delta Z (\cos w \cos\varnothing \sin k)]$$

$$b_{23} = \frac{f}{q} (-m_{11} \Delta X - m_{12} \Delta Y - m_{13} \Delta Z)$$

$$b_{24} = \frac{y}{q}(m_{31}) + \frac{f}{q}(m_{21})$$

$$b_{25} = \frac{y}{q}(m_{32}) + \frac{f}{q}(m_{22})$$

$$b_{26} = \frac{y}{q}(m_{33}) + \frac{f}{q}(m_{23})$$

$$K = \frac{(qy + sf)}{q} .$$

Thus an initial approximations for all the quantities are needed. In the first step the corrections are computed for these parameters and are applied to give more retined values of the parameters. Thus the procedure continues until the corrections become negligible.

C-2 PERPENDICULARITY OF THE FIDUCIAL AXES

With reference to Fig. IV-1, table C-2 gives the comparator/autograph A-8 coordinates obtained by measuring of 35 mm film negative and enlarged photographs of the target field respectively.

35 mm FILM NEGATIVE:

Co-ordinates of the LBC (mm) = 95.22 and 85.165

Co-ordinates of the RBC (mm) = 131.615 and 84.97

Straight line equation fitting the bottom edge

$$y - 84.97 = \left[\frac{85.165 - 84.97}{95.22 - 131.615}\right] (x-131.615)$$

$$y = -0.00535788\ x + 131.32$$

Co-ordinates of the LBC (mm) = 95.22 and 85.165

Co-ordinates of the LTC (mm) = 95.32 and 109.515

Straight line equation fitting the left edge

$$y - 85.165 = \left[\frac{109.515 - 85.165}{95.32 - 95.22}\right](x-95.22)$$

$$y = 243.5\ x - 23100.905$$

$\therefore$ Slope m_1 = -0.00535788

Slope m_2 = 243.5

Point	35 mm Film Negative (Comparator)		Enlarged Photograph (Autograph)	
	x(mm)	y(mm)	x(mm)	y(mm)
LBC	95.22	85.165	0.705	10.99
LTC	95.32	109.515	-3.11	121.20
RTC	131.825	109.275	160.08	125.73
RBC	131.615	84.97	164.75	16.96
A	98.26	87.13	14.29	19.835
B	101.290	89.145	27.675	29.95
C	104.370	91.145	41.51	39.72
D	107.440	93.165	55.03	49.39
E	110.510	95.210	68.57	59.54
F	113.550	97.250	82.205	69.27
G	116.650	99.270	95.48	78.895
H	119.755	101.320	108.705	88.630
I	122.765	103.300	121.48	98.065
J	125.760	105.280	134.55	107.44
K	128.670	107.200	147.02	116.645
L	128.645	87.100	151.48	26.20
M	125.660	89.080	137.88	34.44
N	122.710	91.090	124.20	43.035
O	119.660	93.130	110.25	51.610
P	116.610	95.190	96.25	60.645
Q	113.550	97.250	68.015	78.050
R	110.500	99.305	54.015	86.585
S	107.430	101.360	40.14	95.23
T	104.440	103.390	26.25	104.02
U	101.410	107.405	12.73	112.575

TABLE C-2 : MEASURED COMPARATOR/AUTOGRAPH A-8 COORDINATES OF TARGET POINT IMAGES (FRAME 18).

∴ Angle between the left and bottom edges

$$\alpha = \tan^{-1} \left[\frac{m_1 - m_2}{1 + m_1 m_2} \right]$$

$$\alpha = \tan^{-1} \left[\frac{-0.00535788 - 243.5}{1+(-0.00535788)(243.5)} \right]$$

$$= 89^{0}\ 55'\ 42'' \qquad \text{(C-2.1)}$$

ENLARGED PHOTOGRAPH:

Co-ordinates of LBC (mm) = 0.705, 10.99

Co-ordinates of RBC (mm) = 164.715, 16.96

Straight line equation fitting the bottom edge

$$y - 16.96 \left[\frac{10.99 - 16.96}{0.705-164.715} \right] (x - 164.715)$$

$$y = 0.0364002 + 10.964$$

Co-ordinates of LBC (mm) = 0.705 and 10.99

Co-ordinates of LTC (mm) = -3.11 and 121.20

$$y - 10.99 \left[\frac{121.201 - 10.991}{-3.11-0.705} \right] (x - 0.705)$$

$$y = -28.78859764x + 36.56$$

$$\alpha = \tan^{-1} \left[\frac{0.03640022 + 28.78859764}{1+(0.03640022)(-28.78859764)} \right]$$

$$\alpha = 89^{0}\ 54'\ 17'' \qquad \text{(C-2.2)}$$

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The angles obtained vide equations, (C-1.1) and (C-2.2) establish both in the case of 35 mm negative and its enlarged print that the edges of the exposed photographs are perpendicular to each other. Thus this establishes within acceptable limits the perpendicularity of the Fiducial axes.